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XIV. *Contributions to the History of Explosive Agents.*

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The degree of rapidity with which an explosive substance undergoes metamorphosis, as also the nature and results of that metamorphosis, are, in the greater number of instances, susceptible of several modifications by variations of the circumstances under which the conditions essential to chemical change are fulfilled. Gun-cotton furnishes an excellent illustration of the manner in which such modifications may be brought about. If a loose tuft or large mass of gun-cotton-wool be inflamed in open air by contact with, or proximity to, some source of heat, the temperature of which is about 135° C. or upwards, it flashes into flame with a rapidity which appears almost instantaneous, the change being attended by a dull explosion, and resulting in the formation of vapours and gaseous products, of which nitrogen-oxides form important constituents. If the gun-cotton be in the form of yarn, thread, woven fabric or paper, the rapidity of its inflammation in open air is reduced in proportion to the compactness of structure or arrangement of the twisted, woven, or pulped material; and if it be converted by pressure into compact masses, solid throughout, the rate of its combustion will be still further reduced. If to a limited surface of gun-cotton, when in the form of a fine thread or of a compactly pressed mass, a source of heat is applied, the temperature of which is sufficiently high to establish the metamorphosis of the substance but not adequate to inflame the products of that change (carbonic oxide, hydrogen, &c.), the rate of burning is so greatly reduced that the gun-cotton may be said to smoulder without flame, as shown by me in a communication to the Royal Society in 1864*; the reason being that the products of change, which consist of gases and vapours, continue, as they escape into air, to abstract the heat developed by the burning gun-cotton so rapidly that it cannot accumulate to an extent sufficient to develope the usual combustion, with flame, of the material. For similar reasons, if gun-cotton be kindled in a rarefied atmosphere, the change developed will be slow and imperfect in proportion to the degree of rarefaction, so that, even if an incandescent wire be applied, in a highly rarefied atmosphere, to the gun-cotton, it can only be made to undergo the smouldering combustion, until the pressure is sufficiently increased by the accumulating gases to reduce very greatly the rate of abstraction, by these, of the heat necessary for the rapid combustion or explosion of the substance†.

If, on the contrary, the escape of the gases from burning gun-cotton be retarded, as by enclosing it in an envelope or bag of paper, or in a vessel of which the opening is loosely closed, the escape of heat is impeded until the gases developed can exert sufficient pressure to pass away freely by bursting open the envelope or aperture, and the result of the more or less brief confinement of the gases is a more rapid or violent explosion, and consequently more perfect metamorphosis of the gun-cotton. So, within obvious limits, the explosion of gun-cotton by the application of flame or any highly heated body is more perfect in proportion to the amount of resistance offered in the first instance to the escape of the gases; in other words, in proportion as the strength of the receptacle enclosing the gun-cotton, and the consequent initial pressure developed by the explosion, is increased. Hence, while gun-cotton has been found too rapid or violent in its explosive action when confined in guns, and has proved a most formidable agent of destruction if enclosed in metal shells or other strong receptacles, it has hitherto been found comparatively harmless as an explosive agent if inflamed in open air or only confined in weak receptacles.

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* Proceedings of the Royal Society, vol. xiii. p. 213.

† Ibid. p. 205.

Other explosive compounds, and also explosive mixtures, are similarly influenced, though generally not in such various ways, by the circumstances attending their metamorphosis. Thus the rapidity of the explosion of gunpowder is modified by variations in its density and state of division, and in the degree of facility afforded for the escape of the generated gases, and consequently of the heat which is disengaged during the explosion. Mercuric fulminate may be inflamed in open air upon a piece of very thin sheet metal without indenting it, and furnishes under these circumstances a comparatively feeble explosion; but if even a very much smaller quantity be enclosed in a case or receptacle made of the same description of sheet metal, the latter will be shattered into many pieces when the fulminate is inflamed, and the explosion will be attended by a violent report.

Modifications, apparently slight, of the manner in which the source of heat is *applied* to these explosive agents, when exposed to air under circumstances in other respects uniform, suffice to modify the character of their explosions in a remarkable manner. Thus a modification of the position in which the source of heat is placed with reference to the body of a charge of gunpowder, which is only partially confined, suffice to alter altogether the character of the explosion produced. This is illustrated by the following experiment.

A cylindrical case of sheet tin, 2·5 inches diameter, 6 inches long, and open at one end to its full diameter, was inserted up to its opening in stiff clay soil, which was tightly rammed round it. The cylinder was filled with fine-grain gunpowder (about 1 lb.), and the charge was inflamed by means of a small electric fuse inserted just beneath the exposed surface of powder. The latter burned with a violent rushing sound, similar to, only of much less duration than that produced by the first ignition of a rocket, and indicating a rapidly successive ignition of layers of the powder. The canister was split open in the soldered seam, but was not thrown out of the hole. A small quantity of earth was thrown up, but fell back into the hole. A second corresponding charge of gunpowder was arranged in precisely the same manner as in the preceding experiment, and was inflamed by means of an electric fuse placed at the *bottom* of the charge. A loud explosion was produced; much earth was thrown up and scattered, the bottom of the tin case was found in the crater produced, but the body of the case was not recovered; it had evidently been projected to a considerable distance. In this experiment the main body of the charge obviously acts, at the moment of ignition, as tamping does in a blast-hole, by presenting a resistance to the escape of the gases generated, and thus for a moment establishing the pressure essential to the violent or perfect explosion of the portion of gunpowder first inflamed, whereupon the same character of explosion extends throughout the charge.

Mercuric fulminate furnishes still more striking illustrations of the manner in which the position of the source of heat, with reference to the main body of the explosive material to be inflamed, influences the character of the explosion. In pursuing some experiments, to be presently discussed, on the explosion of gun-cotton, I was led to compare the effects obtained by the explosion of small charges of mercuric fulminate, closely confined, with those produced by comparatively large quantities of that substance freely exposed to air. In firing the latter by means of small electric fuses, I was surprised to find, on the one hand, that a small quantity (0·65 grm.=10 grains) of the fulminate produced occasionally a very much more violent explosion than was obtained with double the quantity of the same fulminate inflamed apparently in the same way, and, on the other hand, that equal quantities of the fulminate, successively inflamed, produced, in one instance, a dull report such as is well known to be furnished when flame is applied to a small quantity of freely exposed fulminate, while in the other instance a very sharp detonation was obtained, like that observed when a small quantity of closely confined fulminate is exploded. Believing that this remarkable difference of result might perhaps be caused by a variation in the force of explosion of the small electric fuse, I substituted a platinum-wire for the latter as the inflaming agent, and still the same variable results were obtained. These were at first thought to be due to a variation in the surface of the fulminate heated at one time, but they were soon traced to variations in the *position* of the source of heat. 1·32 grm. (25 grains) and 2·64 grms. (50 grains) of the fulminate, inflamed by allowing the incandescent wire just to touch the top or edge of the heap, exploded with a dull report, and produced no effect upon the thin flat plate of copper sheet upon which they rested; but about 1 grm. (15·5 grains) of the same fulminate, heaped up over the platinum-wire, produced a sharp and violent explosion, the force of which deeply indented and bent up the support of sheet copper. Equal quantities of the fulminate were made to explode feebly or detonate violently at pleasure, simply by varying their arrangement with reference to the position of the source of heat.

A few substances, of which the metamorphosis into gaseous products and vapours is developed by much less powerful impulses from without than those just instanced, the explosion of which is therefore determined by but little elevation of temperature or by the application of slight disturbing impulses of a mechanical or chemical nature, would appear at first sight only to a small extent susceptible of modifying influences similar to the above. The direct application of but little heat, or the production of a slight increase of temperature by gentle friction or pressure, or by the development of chemical action in some very small portions of the mass, suffices to explode the chloride or iodide of nitrogen, or silver-fulminate; and the explosion of one particle developes an impulse so greatly in excess of that required to disturb the chemical equilibrium existing among the molecules of the mass, that instantaneous decomposition ensues throughout. The great proneness to change of these substances when exposed to a slight disturbing influence, is illustrated by the fact that a concussion imparted to the air in a spacious apartment in which the iodide of nitrogen has been placed, by means of a small explosion or detonation, or even by the violent slamming of a door, suffices to bring about the explosion of that substance. But even if *these* bodies be so confined that an initial resistance is offered to the escape of the gaseous products of their explosion, the violence of the detonation is greatly increased, the development of explosive force being restricted to the instant of rupture of the envelope by the compressed gases. Thus the violence of explosive force exerted by a small quantity of silver-fulminate, confined in a case of stout sheet metal, is very decidedly greater than if a corresponding quantity be enclosed in metal foil, or freely exposed to air and inflamed in the same manner. The violence of explosion of iodide of nitrogen has been found to be very decidedly increased by enclosing it in an evelope or shell of plaster of Paris, or, better still, in a case of sheet metal, while the chloride of nitrogen explodes with but comparatively little violence unless it is confined. The reputation which this substance has enjoyed of being the most violent explosive body known, appears to have been due to the fact that experiments on its explosion have always been conducted with a covering of water upon the material. Three or four drops (about 0·14 grm.=2 grains) placed in a watch-glass covered only with a thin layer of water, explode with a sharp report when touched with turpentine, and almost pulverize the glass; but similar quantities, of which the upper surfaces were exposed to air, have been repeatedly exploded in watch-glasses without breaking the latter. 2 grms. of the chloride, contained in a watch-glass, and covered with a thin layer of water, were placed upon a small solid cylinder of hard *papier maché* which rested upon paving. A violent explosion was produced by touching the chloride with turpentine, the watch-glass was pulverized and dispersed, and the cylinder was greatly shattered, fragments being projected in all directions. 4 grms. of the chloride, with the upper surface exposed to air and placed upon a similar cylinder of *papier maché*, produced a comparatively very feeble explosion; the watch-glass was broken, but the cylinder was not in the slightest degree affected, and remained undisturbed in its original position. A repetition of the experiment with 4 grms. of the chloride, enclosed by a thin layer of water, produced complete disintegration of the cylinder. It appears from these results that in the case of the chloride of nitrogen, the decomposition of which is of an instantaneous character, the resistance offered at the moment by the layer of water acts as effectually in intensifying the force of explosion, as a thin sheet metal case does with the mercuric fulminate, or as a strong iron shell with gun-cotton or gunpowder.

The product of the action of nitric acid upon glycerine, which is known as nitroglycerine or glonoine, and which, as regards its power of sudden explosion, bears some resemblance to the chloride and iodide of nitrogen, appears to be susceptible of only two varieties of decomposition. If a sufficient source of heat be applied to some portion of a mass of this liquid in open air, it will inflame and burn gradually without any explosive effect; and even when nitroglycerine is confined, the development of its explosive force by the simple application of flame or of other sources of heat, by the ordinary modes of operation, is difficult and very uncertain. But if the substance be submitted to a sudden concussion, such as is produced by a smart though not very violent blow from a hammer upon some rigid surface on which the nitroglycerine rests, the latter explodes with a sharp detonation, just as is the case with gun-cotton. Only that portion of the explosive agent detonates which is immediately between the two surfaces brought into sudden collision; the confinement of this portion between the hammer and the support, combined with the instantaneous decomposition of the portion struck, prevent any surrounding freely exposed portions from being similarly exploded by the detonation. A similar result is obtained if *any* explosive compound or mixture be submitted to a sufficiently sharp and violent blow, but the tendency of surrounding particles to become inflamed by the detonation is in direct proportion to the rapidity of explosive action of the substances.

The practical difficulties and uncertainty which attend attempts to develope the explosive force of nitroglycerine by the agency of flame or the simple application of any highly heated body, even when the material is confined in strong receptacles (such as iron shells or firmly tamped blast-holes), appeared fatal to any useful application of the powerful explosive properties of this substance, until M. ALFRED NOBEL'S persevering labours to utilize nitroglycerine, eventually resulted in the discovery of a method by which the explosive power of the liquid could be developed with tolerable certainty. M. NOBEL first employed gunpowder as a vehicle for the application of nitroglycerine. By impregnating the grains of gunpowder with that liquid, he added considerably to the destructive force of the powder when exploded in the usual way, in closed receptacles. M. NOBEL'S subsequent endeavours to apply nitroglycerine *per se* were based upon the belief that its explosion might be effected by raising some portion of a quantity of the liquid to the temperature necessary for its violent decomposition, whereupon an initiative explosion would be produced which would determine the explosion of any quantity of the substance.

I have never succeeded in effecting the *explosion* of nitroglycerine by simply bringing it into contact with an inflamed or incandescent body, but the following results illustrate the manner in which a source of heat may operate in accomplishing the explosion of this substance.

A piece of very thin platinum wire, stretched across between the terminals of two insulated copper wires, was immersed in nitroglycerine; these wires were connected with a BUNSEN battery of five large cells, and a second piece of platinum-wire, similar to that immersed in the liquid, was introduced into the circuit. This was then completed, with the intervention of a long piece of platinum-wire between one of the conducting-wires and the battery. The resistance presented by this interposed platinum-wire was gradually reduced by shortening it, until ultimately the short platinum-wire not immersed in the nitroglycerine was fused. The latter was not exploded nor inflamed, nor was the wire enclosed in it fused, the heat developed in the latter being rapidly absorbed by the surrounding liquid and removed by convection. A very much thicker platinum-wire was now substituted for the thin one and immersed in the liquid; a second short piece was not interposed in the circuit in this instance, but a long platinum-wire, of the same thickness as the above, was employed, as a means of gradually reducing the resistance in circuit. When the length of this wire had been reduced to 5 inches, it was raised to bright redness; this state of things was maintained for about one minute, but the short wire in the nitroglycerine did not glow at the expiration of that period, nor did the liquid exhibit any signs of change, but the glass vessel containing it had become very warm. The long platinum-wire was then removed, and the full battery-power was passed into the short wire immersed in the liquid. After the lapse of about one minute the latter began to assume a brownish colour (like that of a solution of iron), which rapidly deepened, though no red vapours were perceptible in the upper portion of the vessel, until after the lapse of 90 seconds, when the nitroglycerine exploded with great violence.

Attempts were afterwards made to explode nitroglycerine by means of the electric spark. The bare terminals of two insulated wires were immersed in the liquid, in close proximity to each other, and it was endeavoured to pass charges from a Leyden jar; but the insulating power of the liquid prevented the passage of the spark between the immersed points. These were then arranged so as to barely touch the surface of the liquid, and powerful sparks were several times passed, but without result. The sparks from a RUHMKORFF coil with a Leyden jar attached were then allowed to pass uninterruptedly between the poles, which were just touching the liquid, the latter being splashed up by the discharges. In a few seconds the surface of the liquid darkened, and in 30 seconds it exploded.

It is evident from these results that nitroglycerine can only be *exploded* by electric agency or by direct application of any other source of heat, if the intensity of the latter, or the period during which it is applied, suffices to develope decomposition in some portion of the liquid; when once this is established, the temperature is soon raised by accumulation of heat (especially if the application of external heat be continued) until it attains the point at which explosion occurs*.

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* In experiments instituted some time since on the action of heat upon nitroglycerine, I found that a small quantity (one or two drops) of pure nitroglycerine, if exposed to a very gradually increasing temperature, might be raised to 193° C. (380° F.) without the occurrence of an explosion; the liquid sustained slow decomposition

M. NOBEL has described various devices for effecting this so-called *initiative* explosion of some portion of a nitroglycerine charge, of which evidently the most successful are the explosion of a small confined charge of gunpowder, or of a large purcussion-cap, when immersed in or placed immediately over the nitroglycerine. M. NOBEL, however, classes these two modes of ignition in which an explosion or detonation is applied as the exploding agency together with various others in which the simple application of a high temperature to some portions of the nitroglycerine is proposed as the means of explo-

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until it was entirely deprived of explosive properties. A larger quantity enclosed in a sealed tube was exposed for four days to a temperature of 100° C. without exploding. At the expiration of that period the liquid had assumed a brownish colour, but this gradually disappeared altogether after the tube had cooled down; and when the latter was opened after the lapse of some days, there was no pressure of gas, nor did the liquid exhibit the slightest acidity. In this instance the decomposition, probably resulting in the liberation of the nitrogen-oxides, was established by the continued exposure to 100°, and would doubtless, as in the case of the electric experiments, have gradually increased if the application of heat had been continued until the internal development of heat had resulted in explosion.

The difference in the behaviour of nitroglycerine and gun-cotton, when exposed to the influence of a source of heat (apart from the difference in the heat required for their explosion), is evidently due principally to the difference in their physical condition. When a heated body is applied to nitroglycerine, the liquid nature of the latter leads to the distribution through its mass of the heat applied, with rapidity sufficient to render the *ignition* of the but slightly volatile liquid a matter of difficulty, even by the application of a very highly heated body, such as a red-hot wire or rod, or a piece of burning wood; and when the liquid is actually inflamed it burns at first non-explosively, because the increase in temperature of the body of liquid (or of that part presented by the burning surface) which is necessary for developing its sudden decomposition or explosion, takes place only gradually. But if by establishment of a slow decomposition throughout or in some portion of the nitroglycerine, a tendency to disruption of the constituent molecules is developed, the disturbance of chemical equilibrium favours the action of any impulse from without, such as the direct application of heat, so that the *violent explosion* or sudden decomposition of the mass is determined by applying heat to an extent which would, under normal conditions, be quite inadequate to bring about such a result.

In the case of the solid and badly conducting substance gun-cotton, when a source of heat just sufficient for its ignition is applied to any portion, the heat is not diminished by distribution through the mass, hence the particles of gun-cotton contiguous to the source of heat are inflamed almost immediately. If the gun-cotton be in a loose or porous condition (*e. g.* in the form of wool or of loosely wound thread), the entire mass will inflame with such rapidity as to produce a species of explosion, on account of the rapid penetration to the surrounding particles of the heat resulting from the first ignition; but if it be in a compact (compressed) mass, in which the contiguity of particles more nearly approaches that of the particles in the liquid nitroglycerine, the gun-cotton proceeds to burn gradually from the exterior towards the centre of the mass.

If gun-cotton be exposed to a source of heat *insufficient* for its ignition, the heat will gradually accumulate in those parts most contiguous to the source, spreading with comparative tardiness through the mass. A twofold result will then be obtained; heat eventually accumulates to an extent sufficient to establish chemical change in the mass, which becomes greatest near the source of heat, so that, if the application of the latter be not interrupted, the temperature requisite for ignition will be speedily attained in those portions: the result will, however, be no longer the simple inflaming of the gun-cotton with more or less rapidity, but an explosion will ensue, as in the case of nitroglycerine, the violence being proportionate to the heat which has accumulated, and to the extent to which a disturbance of chemical equilibrium has been established.

Frequent confirmations of this view have been obtained in the course of my investigations on the effects of heat upon gun-cotton. The violence of explosion of samples of gun-cotton confined in flasks with not very narrow sion; and although, in his published description of these various methods, he refers to difficulties in developing explosion by those which relate to the simple application of flame or other heated body to the nitroglycerine, yet he refers the effect produced by the confined charge or the percussion-cap only to the heat developed by the ignition of these exploding agents.

The circumstance that nitroglycerine, or any preparation of that substance, may be violently exploded *when freely exposed to air*, by the explosion in contact with it of a small

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necks which had been for some time previously undergoing decomposition (from long-continued exposure to temperatures considerably below its inflaming-point), was always very much greater than would have been the case had gun-cotton in the flasks been ignited by the momentary application of a highly heated body. It would appear, from temperature-observations carried on during experiments of this kind (Phil. Trans. vol. clvii. pp. 197, 223, 226), that in those instances the great violence of explosion was to be ascribed in part to the rapid accumulation of heat in the mass of gun-cotton when the decomposition had reached particular stages; but there can be no question that, at the period immediately preceding the explosion, the gun-cotton was in a state of high chemical tension, and readily susceptible of instantaneous chemical change throughout, just as a Rupert's drop is readily susceptible of violent mechanical disintegration; so that the passage from gradual to instantaneous and therefore most violent decomposition, would occur as soon as the accumulation of heat attained the point at which a sufficient disturbing impulse was imparted to the mass.

The following series of experiments appear confirmatory in their results of the conclusions drawn from the accidental results obtained in the experiments just alluded to.

A wide test-tube was filled to about one-fourth with gun-cotton, the mouth of the tube was left open, and the gun-cotton was inflamed by means of a platinum-wire heated by electricity. A faint explosion was the result, accompanied by a considerable body of flame, and a portion of the gun-cotton was projected from the tube unburned.

The experiment was repeated, the tube being immersed for several minutes in a water-bath at a temperature of 100° C., so that the gun-cotton was raised throughout to that temperature immediately before it was inflamed. The explosion was decidedly, though not very greatly, more vehement than before; the tube was not shattered.

A broad piece of thin platinum-foil, about 2 inches long, was attached by its two sides to copper wires leading to the poles of a battery, sufficient resistance being introduced into the circuit to prevent the foil from being raised to a higher temperature than 90°–100° when the circuit was completed. The wires were approached to each other, so that the strip of foil formed a species of tube open at both ends and down the side. A similar quantity of gun-cotton to that used in the preceding experiments was placed inside this tube, being therefore nearly surrounded by the foil. The whole arrangement was then introduced into a test-tube, like those used in the preceding experiments, and the voltaic circuit was completed. In the course of a few minutes the odour of decomposing gun-cotton was perceptible at the opening of the tube; faint nitrous vapours were soon afterwards observed, and within about fifteen minutes after the first application of heat, the gun-cotten exploded very sharply with only a faint flash, and the tube was shattered and violently dispersed.

The great violence of the explosion at Woolwich, in 1866, of about 140 lbs. of gun-cotton which had been exposed to elevated temperatures for ten months, and of which some packages, very imperfectly purified, were known to be in a state of decomposition at the time (Phil. Trans. vol. clvii. p. 243 *et seq.*), can scarcely be only ascribed to the circumstances that the gun-cotton had been closely packed in strong cases, and that the packages of gun-cotton were at a temperature of about 50° C. at the time of the explosion. When the decomposition, established in some small portion of the gun-cotton, had attained the condition resulting in explosion, a large quantity of the material was in a state of incipient change and, therefore, in a favourable condition for sudden metamorphosis; and this circumstance must have greatly contributed to the suddenness and consequent violence of the explosion.

confined charge of gunpowder, or of a detonating substance, while other modes of explosion by the application of heat or flame, which have been described by M. Nobel, only develope explosion under special conditions, points to a decided difference between the action of the two modes of ignition, and appears to indicate that it is not simply the heat developed by the chemical change of the gunpowder or detonating powder which determines the explosion of the nitroglycerine.

An experimental investigation of this subject has left no doubt on my mind that the explosion of nitroglycerine through the agency of a small detonation is due, at any rate in part, to the mechanical effect of that detonation, and that this effect may operate in exploding the nitroglycerine quite independently of any direct action of the heat disengaged by the gunpowder or other detonating charge.

I was led to examine into this question by an interesting and important observation recently made by my Assistant, Mr. E. O. Brown, in connexion with gun-cotton. The fact that the violent explosion of this substance cannot be developed except when it is confined in receptacles of some strength has been up to the present time accepted as indisputable. It occurred, however, to Mr. Brown that as gun-cotton is analogous in its nature and operation as an explosive agent to nitroglycerine, differing principally from that substance in the rapidity and consequent violence of its explosion, it might also, like nitroglycerine, be susceptible of violent explosion when unconfined, by being ignited through the agency of detonation. This proved to be the case; for upon exploding a small charge of detonating powder in contact with, or in the immediate vicinity to, compressed gun-cotton freely exposed to air, instead of the latter being simply inflamed and then burning gradually, as would be the case if it were brought into contact with flame or any sufficient source of heat, it explodes with great violence, exerting a destructive action equal to that of nitroglycerine, and decidedly greater than that produced by gun-cotton when exploded under the conditions hitherto believed to be those most favourable to the full development of its explosive force. The explosion of a small mass of compressed gun-cotton in this manner suffices to determine the similarly violent and apparently simultaneous explosion of small detached masses of the same material, which may indeed be placed at distances of 0·5 to 1 inch from the original source of the explosion or from each other. Thus, rows of detached masses of gun-cotton, placed on the ground and extending 4 or 5 feet, have been exploded with most destructive results, by the firing of a small detonating tube in contact with the piece of compressed gun-cotton which formed one extremity of the row or train, the explosion of the entire quantity being apparently instantaneous and equally violent throughout.

In the first experiments instituted with the view of ascertaining the conditions to be fulfilled for ensuring the development of the violent action, or for accomplishing the detonation of gun-cotton, when perfectly unconfined, the following points were observed:—

1. If a confined charge of mercuric fulminate be placed in contact with, or buried in gun-cotton which is in the form of wool or spun yarn, its explosion does not develope the violent action of the gun-cotton, as would be the case if the latter were in the form of

a compact, hard and homogeneous mass (as obtained by submitting finely divided gun-cotton to powerful pressure). The light and loose gun-cotton is simply scattered with violence; portions of it are sometimes ignited by the flame of the exploding fulminate, the latter result being obtained with greater certainty, the less violent the detonation produced by the fulminate-charge.

2. The detonation of a small mass of compressed gun-cotton, freely exposed to air, by means of a mercuric fulminate-charge, does not accomplish the explosion of light gun-cotton-wool or yarn placed in immediate contact with it; the latter is scattered and partially inflamed, as in the preceding case*.

3. If the detonation of the fulminate-charge which is placed in contact with a mass of compressed gun-cotton is not sufficiently violent or sharp to effect the explosion, the solid mass is shattered and violently dispersed; if the detonation is upon the verge ot that required for determining the violent explosion of the gun-cotton, no inflammation of the latter takes place; but if the explosion of the fulminate-charge is comparatively feeble, portions of the gun-cotton are inflamed at the moment of dispersion of the mass.

4. Explosive substances which are inferior to mercuric fulminate in the suddenness and consequent momentary violence of their detonation, cannot be relied upon to effect the violent explosion of freely exposed gun-cotton, even if employed in comparatively considerable quantities. Thus, even ordinary percussion-cap composition, which consists of a mixture of mercuric fulminate and potassic chlorate, cannot be used for the detonation of freely exposed gun-cotton unless a much more considerable amount be used than is necessary of pure mercuric fulminate for that purpose. Many other detonating mixtures, exploding less rapidly and violently than the above (*e. g.* very carefully prepared mixtures of sulphide of antimony, potassic ferro- and ferricyanides, plumbic ferrocyanide, and potassic picrate, with the chlorates), have been tried without success in very considerable quantities, as agents for developing the detonation of gun-cotton in open air.

5. The quantity of confined mercuric fulminate required to effect the detonation of freely exposed gun-cotton, is regulated by the degree to which the sharpness of its explosion is increased by the extent of accumulation of force, consequent upon the strength of envelope in which the fulminate is confined. From 1·3 to 2·0 grms. (20 to 30 grains) are required to detonate the gun-cotton, if the fulminate be confined in a thin case of wood, or in several wrapping of paper, while the same result can be produced with 0·32 grm. (5 grains) if that amount be confined in a cap of thin sheet metal.

If the fulminate be placed in a wide paper cylinder open at the top, which is rested upon the gun-cotton-surface, or if it be placed in a heap directly upon the surface of gun-cotton, and if in either instance the violent explosion of the fulminate be effected through the agency of a platinum-wire placed at the *base* of the heap, about 2 grms. (25 to 30 grains) of fulminate will also accomplish the detonation of the gun-cotton, the violent action of the fulminate being, in these instances, developed by the confinement of the portions first ignited in a weak envelope, which consists partly or entirely of the surrounding or superincumbent fulminate (see p. 491)*.

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* If two disks of compressed gun-cotton be firmly attached to opposite sides of the metal case which contains the minimum charge of fulminate required to produce detonation, when confined, the desired result will be produced; but if the disk be simply rested loosely against the sides of the metal case, they will only be violently thrown aside.

6. It need perhaps scarcely be stated that the degree of proximity of the detonating charge to the gun-cotton, which is essential for the explosion of the latter, is regulated by the violence of the detonation produced. 0·32 grm. (5 grains) of fulminate enclosed in a metal cap must be placed in close contact with (*i. e.* closely surrounded by) the unconfined gun-cotton, in order to effect its explosion, while 1·3 grm. (20 grains), similarly confined, will produce the same result if placed at least 0·5 inch distant from the surface of the compressed gun-cotton.

The foregoing facts appear to point to the mechanical action of a detonation as being the real cause of the violent explosion of freely exposed gun-cotton or nitroglycerine. At any rate they appear to indicate decisively that such explosion is not a result of the direct application of the heat developed by the explosion of the detonating materials. If it were so, then the detonating mixture described as percussion-cap composition, and other explosive mixtures, the ignition of which is attended by much greater development of heat than is obtained by the ignition of pure mercuric fulminate, should explode freely exposed gun-cotton more readily than the latter does; the readiness with which the gun-cotton is exploded should be solely proportionate to the amount of fulminate employed; and gun-cotton should be more readily exploded in the loose and open condition than in the compact and highly compressed form; for the latter presents it in the condition least favourable, and the former that most favourable to ready and rapid ignition by heat. Again, the actual temperature required for the explosion of nitroglycerine is very considerably higher than the exploding temperature of gun-cotton; the former may be heated to a temperature of 193° C. (380° F.) for some time without exploding, while the latter inflames at a temperature of 150° C., yet a much smaller charge (not more than 0·2 of the amount) of fulminate suffices for the explosion of unconfined nitroglycerine than it needed for the detonation of gun-cotton†. On the other hand, a quantity of confined percussion-cap composition which, if it were pure mercuric fulminate, would be altogether inadequate for the detonation of gun-cotton, suffices for the detonation of nitroglycerine.

Although the foregoing facts appear to afford indisputable evidence that the direct application of heat, from an exploding charge of detonating powder, is not concerned in developing the violent action of gun-cotton or nitroglycerine, an attempt has been made to devise some experiments in which the detonation of either of those substances by the agency described should be accomplished in such a manner as to interpose an effectual barrier between the material to be exploded and the heated gases or flame resulting from the ignition of the charge of fulminate destined to furnish the initiative detonation.

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* 3·24 grms. (50 grains) of the fulminate heaped upon the gun-cotton-surface as in the above experiments, but inflamed at the top of the heap, failed to explode or even to inflame the gun-cotton.

† About 3·24 grms. (50 grains) of *chloride of nitrogen*, confined by water, are required for the detonation of gun-cotton, whereas 0·1 grm. (1·5 grain) of the chloride, similarly confined, suffices to detonate nitroglycerine.

Some small pellets (0·5 inch in diameter) of compressed gun-cotton saturated with nitroglycerine were placed in a cylindrical wooden case open at one end and fixed at the bottom of a trough of water; the air-spaces between the separate pellets were thus occupied by water, the height of which above the charge was about one foot. An electric fuse, primed with 2·6 grms. (40 grains) of mercuric fulminate and rendered thoroughly waterproof by being coated with a cement composed of gutta percha and pitch, was weighted and placed at the bottom of the trough, on one side of the cylinder and at a distance of 2 inches from it. The detonation of the fulminate did not explode the charge; the experiment was then repeated, the water-space which intervened between the fuse and the wooden cylinder being reduced to 1 inch. In this instance the firing of the fuse exploded the immersed pellets, the water was projected to a great height, the trough was broken into small fragments, and a crater was formed in the ground upon which it rested. This experiment was repeated with the same results. A small cylinder about 1 inch in diameter and 2 inches long of compressed gun-cotton, saturated with nitroglycerine, was enclosed in a paper case, which was thickly coated with the gutta-percha cement. A screen of thin sheet copper, 4 inches square, was placed at the bottom of a trough and the waterproofed charge of explosive material was weighted and placed upon one side of the screen at 0·25 inch distance from it. A waterproofed electric fuse primed with 2·6 grms. (40 grains) of mercuric fulminate was placed on the other side of the screen at a distance of 1 inch from the latter; the trough was then filled with water, so that the screen, charge, and fuse were each surrounded and separated by the liquid. In the first experiment, the explosion of the fuse did not affect the charge, but upon repeating the experiment with a fuse placed at a distance of 0·75 inch from the screen, the charge was violently exploded as in the former experiment.

A precisely similar experiment was tried with cylinders consisting of compressed gun-cotton only, and enveloped in coatings of some thickness of the gutta-percha cement; but even when the charge and the fuse were placed close to the sides of the screen which separated them under water, the gun-cotton was not exploded by the detonation of the fulminate; the same negative result was obtained when a fuse (enveloped in the waterproof coating) was placed immediately upon a gun-cotton charge enclosed in the paper case and waterproof cement, and exploded under water or in open air. These negative results were instructive, as indicating that the thick yielding envelope which enclosed the gun-cotton charge (possibly assisted by the thin air-cushion by which the enclosed charge was also surrounded) served to protect the comparatively less sensitive explosive material, gun-cotton, by reducing or absorbing the power of the blow or concussion (or whatever the disturbing impulse may be). The same description of envelope did not protect the more readily explosive substance, nitroglycerine, as the preceding experiment showed.

A cylinder of gun-cotton, enclosed in a water-tight case of thin sheet metal, and immersed in water, was violently exploded by a fulminate-fuse which was placed by its side, with about 0·25 inch of intervening water. In this instance, therefore, the exploding power of the fuse was not absorbed by the envelope which enclosed the gun-cotton.

Some nitroglycerine, contained in a glass beaker, was placed at the bottom of a trough filled with water; a fulminate-fuse, placed at a distance of 2 inches from the side of the beaker, failed to fire the nitroglycerine; but when the intervening water was reduced to little more than 1 inch, the detonation of the fuse exploded the nitroglycerine.

A 12-pound cast-iron shell (0·75 inch thick, and 4·45 inches internal diameter) was filled about one-half with small granules of gun-cotton impregnated with nitroglycerine. The shell was then filled with water, and a waterproof fulminate-fuse was inserted through the plug which closed the shell. The fuse and each separate granule of the explosive agent were therefore surrounded by water. Upon ignition of the fuse, the shell (which was placed in a very strong room) exploded with a violent report, and was broken into very small fragments, the greater number of which were buried in the timber which lined the cell.

A similar shell was half filled with the same explosive agent; the spaces between the granules and the empty portion of the shell were then filled with a thin plaster of Paris mixture, and a fulminate-fuse was imbedded in the solid plaster which filled the upper half of the shell. The explosion of the fuse was attended by a precisely similar result to that obtained in the preceding experiment.

It is believed that these experiments, together with the facts regarding the behaviour of gun-cotton which have been stated in the earlier part of this paper, afford convincing proof that the violent explosion of gun-cotton and nitroglycerine through the agency of a detonating fuse must be ascribed either to the mechanical effect of that detonation (*i. e.* to the work done upon the particles more immediately exposed to the blow or concussion of the detonation), or to the development of a disturbance of chemical equilibrium in the explosive agent by the suddenness and peculiar character of the concussion, or by the powerful vibrating impulse which the detonation establishes.

The readiness and certainty with which gunpowder, gun-cotton, and other explosive substances may be detonated through the agency of a blow from a hammer or a falling body, are regulated by several circumstances; they are in direct proportion to the weight of the falling body, to the height of its fall, or the force with which it is impelled downwards, to the velocity of its motion, to the mass and rigidity, or hardness, of the support or anvil upon which the body falls; to the quantity and mechanical condition of the explosive agent struck, and to the ready explosibility of the latter. Thus a sharp blow from a small hammer upon an iron surface will detonate gunpowder with very much greater certainty than the simple fall of a heavy hammer, or than a comparatively weak blow from the latter. It is very difficult, by repeated blows applied at very brief intervals, to ignite gun-cotton, if placed upon a support of wood or lead, both of which materials yield to the blow, the force set into operation by that blow being transferred through the explosive agent and absorbed in work done upon the material composing the support. If, however, the latter be of iron, which does not yield permanently to the blow of the hammer, the detonation of these substances is readily accomplished. If the quantity of explosive agent employed be so considerable as to form a thick layer between the hammer and support, the force applied appears to be to so great an extent absorbed in the motion imparted to the particles of the compressible mass, that its explosion is not readily accomplished; and if the material be in a loose or porous condition (as, for example, in a state of powder or of loose wool), much work has to be accomplished in moving particles of the mass through a comparatively considerable space, and a second or even third blow is therefore required to determine its explosion.

These circumstances would appear to afford support for the belief that the detonation of an explosive material through the agency of a blow is the result of the development of heat, sufficient to establish energetic chemical change, by the expenditure of force in the compression of the material, or by the friction of the particles against each other, consequent upon a motion being momentarily imparted to them. It is conceivable that, from either of these causes, sufficient heat may be accumulated with almost instantaneous rapidity, in some portion of the mass struck, to develope sudden chemical change*. The circumstance, that the detonation of those portions of an explosive compound (such as gun-cotton or nitroglycerine) which are immediately between the surfaces of the hammer and the support is not communicated to the surrounding portions, may be ascribed to a combination of two causes, the instantaneous nature of the explosion, and the close confinement of the portions struck at the instant of their explosion. The mechanical effect of the detonation is absorbed by the masses of metal between which it occurred, and the gases developed disperse the surrounding portions of the explosive agent, as they rush away from between the two surfaces. It is possible also to detonate gunpowder and other explosive mixtures by a blow in such a manner that only the portions immediately struck are ignited; but those substances may also be exploded, though much less violently, by a less sudden or powerful application of force, in which case they detonate much more feebly; their explosion is accompanied by a larger volume of flame, and by the ignition of those portions which surround the part struck by the hammer.

The exceedingly violent motion of particles resulting from the sudden or extremely rapid transformation of a solid or liquid explosive body into highly expanded gas or vapour, must obviously exert a force which operates upon a resisting body, in the vicinity, in a manner precisely similar to the force applied by opposing a body in the path of a solid mass which is set into very rapid motion. In other words, a detonation exerts a mechanical effect upon resisting bodies precisely similar to that of a blow, as from a falling hammer or a projectile propelled from a gun. Just as the force of a sufficiently sudden or powerful blow from a hammer is transformed into heat by the resistance to the motion of the hammer which the particles of an opposing body present, and by the consequent friction established between those particles, so the force or concussive action exerted by the matter set in motion when a solid or liquid is converted into gas or vapour, will also be transformed into heat, the development of which in an opposing body will be proportionate to the resistance to motion which its particles offer, and to the suddenness and violence of the concussion to which it is subjected.

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* In illustration of the effect of friction of particles of a mass against each other in determining the development of an explosion, the following experiment may be quoted. A very porous pellet of a mixture of potassic chlorate and amorphous phosphorus (carefully purified from ordinary phosphorus) was placed between two polished metal plates, and a somewhat rapidly accumulating pressure was then applied; the mass exploded almost directly, before, in fact, sufficient force had been expended to convert the loose aggregate of particles into a compact mass. A second similar pellet, also placed between two polished surfaces, was submitted to pressure very gradually and carefully applied, and was thus converted into a compact mass without being exploded; on afterwards submitting this to rapidly increasing pressure precisely as in the first experiment, a much more considerable accumulation of force was required to accomplish the explosion of the mass.

The power of accomplishing the explosion or detonation of gun-cotton or nitroglycerine in open air through the agency of a detonation produced in its vicinity, would therefore appear to be correctly ascribable to the heat suddenly developed in some portion of the mass by the mechanical effect, or blow, exerted by that detonation, and would seem to be regulated by the violence and suddenness (either singly or combined) of the detonation, by the extent to which the explosive material is in a condition to oppose resistance to the force, and by the degree of sensitiveness of the substance to explosion by percussion.

The following points appear to support this view:—

1. Gun-cotton, freely exposed, cannot be detonated by any explosive agent less sudden and violent in its action than mercuric fulminate. Explosive mixtures (such as percussion-cap composition, see page 498, and mixtures of potassic chlorate with potassic picrate, &c.) which are apparently but little inferior to the fulminate in the rapidity of their explosive powers, will not detonate gun-cotton even though confined charges of them, amounting to about ten times the quantity of mercuric fulminate required to produce the effect with perfect certainty, are employed.

2. On the other hand, nitroglycerine, which is much more readily exploded by a blow than gun-cotton, may be detonated through the agency of explosive mixtures less violent and sudden in their action than the fulminate. A quantity of percussion-cap composition, about one-half that of the minimum of fulminate required to detonate gun-cotton, will suffice to detonate nitroglycerine.

3. If the suddenness of the detonation produced by means of mercuric fulminate be increased, as described at page 490, by its confinement in a strong envelope, a very much smaller quantity suffices to develope the detonation of gun-cotton than if the fulminate be exploded in open air, or in an envelope which offers but slight initial resistance.

4. The mechanical condition of the gun-cotton most materially influences the result obtained by its exposure to detonation. A considerable compactness or density, and a consequently great resistance to motion of the particles, is essential for the detonation of gun-cotton, as pointed out at page 497.

There are, however, several well-known facts, and some results of experiments instituted with special reference to this subject, which do not appear to be in harmony with the assumption that the detonation of nitroglycerine and gun-cotton in the manner described is simply due to the *suddenness* of the development and application of physical force. The following are some of the more important facts of this kind:—

1. The circumstance that the explosion of mercuric fulminate accomplished the detonation of gun-cotton, whereas explosive agents less sudden in their action failed to furnish this result, appeared to render it probable that silver-fulminate, which explodes more suddenly and with much more powerful local force when applied under the same conditions, would accomplish the detonation of gun-cotton more readily than the mercury-compound, *i. e.* it was anticipated that a larger amount of the latter would be needed, than of silver-fulminate, to produce the desired effect. This proved, however, not to be the case; though apparently not inferior, the silver compound is in no way superior to that of the mercuric fulminate. The minimum quantity of the latter which can be relied upon to detonate compressed gun-cotton is 0·324 grm. (5 grains), and it is necessary to enclose that quantity in a case of stout sheet metal, and to place it in close contact with the gun-cotton in order to obtain the desired result (see page 499). 0·324 grm. (5 grains) of silver-fulminate enclosed in tin-foil, though it appeared to produce quite as sharp a detonation as the corresponding quantity of mercury-salt confined in the stout case, did not explode gun-cotton with which it was closely surrounded, but merely shattered and dispersed the mass. But when enclosed in the stout sheet-metal cap, the 0·3 grm. of silver-fulminate accomplished the detonation of gun-cotton.

2. Iodide of nitrogen, as one of the most sensitive and, apparently, violently explosive compounds with which we are acquainted, was next experimented with. The susceptibility to sudden explosion even of silver-fulminate will not bear comparison with that of the iodide of nitrogen or of the corresponding chlorine compound, though, as regards the mechanical effect of the explosion (*i. e.* its local destructive action) both of those compounds accomplished decidedly less work than the silver-fulminate under the same conditions (see page 508).

Many unsuccessful attempts have been made to explode gun-cotton through the agency of iodide of nitrogen. Pellets of this substance (weighing about 0·2 grm. and 0·35 grm.[*]), resting upon paper or thin cardboard, were carefully placed, when perfectly dry, upon compressed gun-cotton, and were then exploded by being touched with the end of a long rod; the compact masses of gun-cotton were more or less disintegrated by the explosions, but no detonation resulted. Indications having been obtained that the violence of explosion of the iodide was decidedly increased by its confinement (see p. 492), two descriptions of small shells charged with the substance were prepared. About 1 grm. of the iodide was placed, while moist, in a small cup of plaster of Paris, a spherical mass of the plaster was then formed round this, so that after a time the explosive agent was enclosed in a hard shell, the walls of which were about 0·3 inch in thickness. The shells thus produced were confined for several days in proximity to a desiccating agent, until it was found by trial of the shells that the perfect desiccation of the iodide of nitrogen through the porous plaster shell has been accomplished. These shells were then allowed to fall from heights of 4 feet and 20 feet upon masses of compressed gun-cotton; their explosion simply shattered the latter.

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[*] The weights of the masses of iodide of nitrogen used were estimated by first ascertaining the average loss sustained by desiccation of the substance after gentle pressure between bibulous paper, and making allowance for this loss in the quantities of iodide set aside to dry for experiment.

Short tubes of stout sheet copper open at one end only, were charged with 0·75 grm. of the moist iodide, and they were then closed with thick plugs of plaster or of tightly compressed bibulous paper. When the moisture had been entirely abstracted from the enclosed iodide through the porous plugs, the shells were carefully transferred to the surfaces of pellets of compressed gun-cotton, placed under the lower opening of a vertical iron pipe 20 feet in height, and a weight was allowed to fall down the pipe upon them. The shells exploded violently and were broken up and dispersed; but no detonation of the gun-cotton was effected. The same negative result was obtained with a similar shell charged with 1 grm. of the iodide.

6·5 grms. (100 grains) of this substance were pressed firmly together while moist, and heaped upon the upper surface of a pellet of compressed gun-cotton 1·25 inch in diameter, which rested upon a flat copper plate 0·05 inch thick. This plate was placed upon a thick layer of pumice-stone fragments, saturated with concentrated sulphuric acid. This arrangement was situated in open air, and was enclosed under a box which could be readily and quietly withdrawn from a distance by means of a cord; immediately over it was fixed a small vessel containing sand, which could be discharged so as to fall upon the iodide of nitrogen by the pull of a string. After the lapse of five days (during dry weather), when it was judged that the iodide of nitrogen had dried, the box was withdrawn and the sand allowed to fall; a very sharp explosion was the result, but it was evident from the character of the sound that this was due to the explosion of the iodide only. The gun-cotton pellet was found to have retained sufficient moisture (absorbed from the iodide) to interfere with its explosibility; the result of the experiment was therefore not decisive, but it afforded an excellent illustration of the force exerted by the explosion of that quantity of iodide of nitrogen. The stout copper plate upon which the pellet rested was bent into the shape of a watch-glass; the gun-cotton pellet (which had been produced from the pulp by a pressure of about four tons on the square inch) was driven into the plate so as to indent the latter considerably, and a sharp impression of some small indentations existing upon the copper surface was found upon the lower surface of the pellet.

The foregoing experiment was repeated with this difference, that the charge of iodide of nitrogen was placed in a flat-bottomed capsule of very thin platinum-foil, the lower surface of which was in close contact with the pellet of compressed gun-cotton. The latter was placed upon a flat copper plate (precisely similar to that used in the preceding experiment), which rested upon a thick layer of fused chloride-of-calcium fragments.

After a lapse of five days the box which covered this arrangement was withdrawn and the iodide was exploded as before, without accomplishing the detonation of the gun-cotton. As in the former instance, the compressed pellet was driven into the copper plate and moulded to the cup-shaped indentation produced. The gun-cotton proved in this instance to be perfectly dry; this experiment therefore demonstrated decisively that the detonation could not be accomplished even by so large a quantity as 6·5 grms. of iodide of nitrogen.

3. The following experiments were made with chloride of nitrogen, for the purpose of comparing its power to accomplish the detonation of gun-cotton with that of the explosive agents already discussed. About 0·65 grm. (10 grains)* of the chloride were transferred to a thin watch-glass and covered with a film of water (see p. 492); the watch-glass was placed upon the upper surface of a pellet of gun-cotton which rested upon the ground. The chloride of nitrogen was then exploded by means of a long rod the extremity of which was moistened with turpentine. The glass was shattered and dispersed by the explosion, but the mass of gun-cotton was only to a slight extent disintegrated. 1 grm. (15·4 grains) of the chloride was next employed in precisely the same manner; the gun-cotton pellet was not exploded, but was much shattered by the explosion. About 2 grms. (31 grains) of the chloride, applied as before, did not explode the gun-cotton, but the pellet was completely broken and violently scattered. A corresponding quantity of the chloride, of which the surface was directly exposed to air, broke the watch-glass into numerous fragments, but did not in any way affect the gun-cotton pellet, which was not even moved from its original position. 3·25 grms. (50 grains) of the chloride were next employed in the same manner as the foregoing charges (*i. e.* contained in a thin watch-glass and covered with a film of water); in this instance the gun-cotton was detonated by the explosion of the liquid. The experiment was repeated with what was estimated to be the same quantity of chloride of nitrogen; the gun-cotton pellet was not exploded, but was completely disintegrated and scattered, the effect being the same as that produced with an amount of mercuric fulminate just below that required to accomplish the detonation of gun-cotton. It would appear therefore that 3·25 grms. (50 grains) of chloride of nitrogen, covered with water, is about the minimum quantity required to accomplish the result attainable with 0·32 grm. of mercuric fulminate enclosed in a metal case.

The foregoing results obviously do not support the view that the suddenness or sharpness of a detonation alone favours the development of violent explosive force from gun-cotton in open air. The silver-fulminate produces a much sharper explosion than the mercuric fulminate, yet it was not found that a smaller quantity of the former than of the latter was required for the detonation of gun-cotton. The explosion of the iodide and the chloride of nitrogen is certainly more sudden than that of the above fulminates, unconfined, and at any rate equally so with the confined fulminates; yet it was not found possible to detonate gun-cotton by the explosion of 6·5 grms. (100 grains) of the iodide, in contact with it, and 3·24 grms. (50 grains) of chloride of nitrogen, *confined by water*, were required to accomplish the result attained by 0·32 grm. of either of the confined fulminates, or by 2 grms. of the mercuric fulminate, unconfined by any strong envelope (p. 499).

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* The weights of the quantities of chloride of nitrogen employed were closely estimated by ascertaining the weight of corresponding volumes of liquid having the same specific gravity as the chlorine compound. In the experiments with chloride of nitrogen, I had the advantage of assistance from my friend Professor BLOXAM.

With the view of ascertaining whether the relative power of different explosive agents to accomplish the detonation of gun-cotton appears to be in direct proportion to the relative mechanical effects of their explosion (*i. e.* to the work performed by them upon a body placed in contact with them), a series of experiments was instituted with the object of comparing this particular action of the several explosive materials.

A thin and uniform copper sheet was cut up into square pieces of equal dimensions, and these were similarly supported at their corners only. Equal quantities of the four different explosive agents, the mercury- and silver-fulminates and the chloride and iodide of nitrogen, were employed; in the case of the two former the weights were directly determined, but in the case of the latter they were estimated as accurately as possible by the methods given at pages 504 and 506. In some experiments the fulminates were placed in direct contact with the copper, in others, with the view of comparing them accurately with the iodide of nitrogen, they were placed upon thin cards which rested upon the sheet copper. The iodide of nitrogen was always used in this way, but as for obvious reasons the chloride of nitrogen could not be thus employed, it was placed in very thin watch-glasses which rested upon the copper sheet. The force brought to bear upon the copper support was obviously not diminished to any important extent by the expenditure necessitated in the fracture of the thin glass surface.

The following are the results deduced from repeated experiments with a series of different proportions of the several explosive agents.

The mechanical effect of the explosion of silver-fulminate in small quantities, *freely exposed to air*, was decidedly greater than that of the other three substances when exploded under the same conditions. 0·07 grm. (1 grain) of this fulminate produced a deep and very sharply defined indentation in the copper sheet. A corresponding quantity of the iodide of nitrogen, made to cover about the same surface of the sheet metal, produced a decidedly less deep and more rounded indentation. The explosion of an equal quantity, and even more than double that amount, of chloride of nitrogen, with its surface freely *exposed to air*, did not even break the thin watch-glass which contained it; if, however, similar quantities of the liquid were covered with a thin layer of water, their mechanical action upon the copper was decidedly greater than that of the exposed iodide. 0·07 grm. (1 grain) of mercuric fulminate, freely exposed, produced no effect whatever upon the copper sheet, but if enclosed in a thin case of sheet metal, its mechanical action was greater than that of silver-fulminate when exposed to air. 1 grm. (15·5 grains), 1·62 grm. (25 grains), and 3·24 grms. (50 grains) were exploded without producing any indentation upon the copper, provided that the little heap was inflamed by the application of a heated body to some portion of their *exposed* surfaces; but if the source of heat was situated at the base of the heap, being entirely enclosed by the fulminate, a very sharp explosion was produced instead of a dull muffled report, and the mechanical effect upon the copper approached in extent that produced by corresponding quantities of chloride of nitrogen confined by a thin layer of water, though it was still much inferior to that produced by freely exposed silver-fulminate, exploded by its surface being touched with sulphuric acid. The destructive effect of the mercuric fulminate was still further increased by placing the charge in a short wide paper cylinder, freely open at the upper end, and with the source of heat (platinum-wire) buried deeply in the charge (see p. 498). But the mechanical effects produced by mercuric fulminate, exposed to air and inflamed from beneath as described, were not to be compared to those obtained by enclosing it in cases of sheet metal. 0·15 grm. (1 grain), thus confined, produced an effect upon the copper sheet somewhat greater than that of a corresponding quantity of the silver-fulminate, freely exposed; and a charge of 0·32 grm. (5 grains), similarly confined, was about equal in violence of action to 1 grm. (15 grains) of the unconfined material inflamed at the base of the heap. A comparison of the effects of larger quantities of the several explosive agents confirmed the foregoing results. Thus 0·28 grm. (4 grains) of unconfined chloride of nitrogen exerted much less destruction than an equal quantity of unconfined iodide of nitrogen; but if the former was confined by a thin layer of water, it was considerably more violent in its action than a corresponding quantity of the unconfined silver-fulminate. The 0·28 grm. (4 grains) of mercury-salt produced no effect upon the copper support; but a similar quantity confined in a metal tube, exerted a destructive action about equal to that of the unconfined silver-fulminate.

1 grm. of iodide of nitrogen and a similar quantity of chloride of nitrogen, covered with a film of water, did no more work than 0·5 grm. of unconfined silver-fulminate; and the effect of the latter was exceeded by that of a similar quantity of the mercury-salt confined in a stout sheet-metal cylinder, while 1 grm. of the latter, freely exposed but inflamed at the base of the heap, exerted a destructive action somewhat inferior to that of the enclosed chloride of nitrogen.

It would appear, therefore, from these experiments, that, when unconfined, the violence of explosion of chloride of nitrogen is less than that of the iodide, and that, if confined under water, it very considerably exceeds that of the exposed iodide, but falls very short of that exerted by unconfined silver-fulminate. It also appears that the mercuric fulminate, which is much less rapidly explosive than either of the other substances, exerts less mechanical force than any of them, if freely open to air, and if inflamed at some portion of the exposed surfaces; if ignited at the lower inner portion of the mass, where the part first inflamed is enclosed by the mass of the material itself, it exerts a destructive force little inferior to that of the chloride of nitrogen enclosed by water; but if confined in a strong envelope (*e. g.* of sheet tin), the mercuric fulminate is greater in violence of action than the unconfined silver-fulminate.

These results to a great extent confirm the correctness of the view that the readiness with which the detonation of gun-cotton is accomplished is in proportion to the mechanical force exerted by the initiative detonation to which it is subjected. The force exerted by small quantities of strongly confined silver- and mercuric fulminate greatly exceeds that developed by the explosion of comparatively large proportions of the iodide and chloride of nitrogen. This may be accepted as accounting, to some extent, for the fact that the detonation of gun-cotton could not be accomplished by an amount of iodide of nitrogen twenty times greater than that of fulminates required for the purpose, while ten times the quantity of the confined chloride were required to produce the result. That the quantity of mercuric fulminate required to produce detonation is reduced in proportion as means are applied to increase the violence of the force exerted by it at one time, is quite in accordance with the above view.

Several curious and apparently anomalous effects were, however, observed in the course of the numerous experiments referred to in this paper, which suggest the inquiry whether there may not be some peculiarity in the concussion or powerful vibration produced by a particular kind of explosion, which acts apart or distinct from the mechanical force of that explosion in developing or promoting the detonation or sudden chemical disintegration of the molecules of a neighbouring explosive body.

The results of a few experiments instituted with nitroglycerine appear to furnish a decided affirmative reply to that inquiry. A comparison was in the first instance instituted between the mechanical action of the explosion of nitroglycerine, and of the other materials which have been discussed. The charges of nitroglycerine were introduced into small wide tin tubes, freely open at the upper end or closed by means of a cement, and their explosion was accomplished by the detonation of a small percussion-cap, just immersed in or resting upon the liquid, and containing 0·07 grm. (1 grain) of mercuric fulminate. Nitroglycerine thus detonated produced a destructive effect upon the copper support very greatly exceeding that obtained with the same amount of unconfined silver-fulminate. As the mechanical force developed by nitroglycerine was so very considerable, and as, moreover, the character of its detonation might be expected to bear some analogy to that of gun-cotton, it was considered probable that the latter might prove susceptible of detonation by a much smaller proportion of nitroglycerine than it is necessary to employ of the confined fulminates. No success, however, attended repeated attempts to explode gun-cotton by the detonation of 0·07 grm. (1 grain) and increasing charges up to 0·65 grm. (10 grains) of nitroglycerine. At the same time these results were not quite conclusive, as it was not found easy to ensure the complete detonation of the liquid by the small fulminate-charge, on account of the difficulty of securing a favourable adjustment of the detonating cap and the very small quantity (from two to ten drops) of nitroglycerine used. The experiments were therefore repeated with corresponding quantities of the liquid converted into a thick paste by admixture with sand, in tin tubes similar to those previously used. The explosion of the nitroglycerine appeared to be rendered more certain by this contrivance, but in order more thoroughly to ensure its proper detonation, the charge of mercuric fulminate used for that purpose was increased to 0·14 grm. (2 grains). Still the detonation of gun-cotton could not be accomplished, although the charge of nitroglycerine was gradually increased to 1 grm. The disk of compressed gun-cotton which rested upon a support of wood was shattered almost to dust, portions being driven deeply into the wood, which exhibited an indentation corresponding to the form of the disk. In order to compare the mechanical effect of the detonation of nitroglycerine with that of the strongly confined fulminates, 0·65 grm. (10 grains) of the liquid were placed in the small tin tube upon stout sheet copper and detonated by means of 0·14 grm. (2 grains) of mercuric fulminate; the work done upon the copper resembled in extent that accomplished with a corresponding charge of the confined fulminate (double the amount required to effect the detonation of gun-cotton). It appeared evident, therefore, that some power, apart from violence of explosion, was wanting in nitroglycerine to produce the result obtained with the fulminate. With a view to obtain still more decided evidence on this point, the experiments were continued upon a larger scale. Some four-ounce (124·5 grms.) disks of compressed gun-cotton were placed upon thick supports of wood, and confined charges of nitroglycerine, weighing about 0·75 ounce (23·3 grms.),were placed upon these disks and successively exploded. The pieces of wood were more or less shattered; they were deeply indented (the circumference of the disk being clearly imprinted upon them), and the gun-cotton was pulverized and violently scattered, portions being driven firmly into the wood, but the desired result was not in any instance accomplished. As a last experiment, the wooden support bearing the disk of gun-cotton with the vessel containing (23·3 grms.) 0·75 ounce of nitroglycerine, was buried about 6 inches in the ground, the stiff clay soil being firmly pressed over the whole. The explosion of the nitroglycerine threw the earth up violently, the piece of timber was split across the fibre and shattered in the centre, and the gun-cotton, in a fine state of division, was found disseminated in the earth and partly forced into the wood *.

In contrast to the foregoing results, it may be mentioned that small perforated cylinders of compressed gun-cotton, weighing 7·75 grms. to 15·5 grms. (0·25 oz. to 0·5 oz.), with the usual small confined charge of mercuric fulminate inserted into the perforation, have frequently been employed, and invariably without failure, for effecting the detonation of a large disk or slab of gun-cotton, or of a number arranged side by side in open air, by simply placing them upon or against any one of the surfaces of the larger mass of gun-cotton. It should also be stated that the detonation of a small quantity of nitroglycerine has been found to accomplish the simultaneous explosion of surrounding charges of that substance closely confined in small vessels of sheet tin, and placed at distances of 2 or 3 inches from the central charge. Lastly, it was found that the detonation of 7·75 grms. (0·25 ounce) of gun-cotton determined the explosion, simultaneously with it, of a charge of nitroglycerine confined in a vessel of sheet tin and placed at a distance of 1 inch from the gun-cotton, while 15·5 grms. (0·5 ounce) of the latter produced the same result when separated from the confined nitroglycerine by a space of 3 inches. All these experiments were so conducted that indisputable evidence was

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* These experiments were repeated with 1 ounce of nitroglycerine, with the same results.

obtained when the charges had been exploded, or were merely scattered, by the force of the detonating charge. It was found in every instance quite impossible to distinguish any difference in the suddenness or sharpness of the report produced when the detonating charge alone was exploded, and when it accomplished the simultaneous firing of neighbouring charges.

The results obtained with nitroglycerine in attempts to detonate gun-cotton through its agency, appear to me to substantiate the view which has obtruded itself repeatedly on my mind upon consideration of many of the phenomena observed in the experiments detailed in this communication, namely, that a particular explosion or detonation may possess a power of determining at the instant of its occurrence similarly violent explosions in distinct masses of the same material, or in contiguous explosive bodies of other kinds, which power is independent of, or auxiliary to, the direct operation of mechanical force developed by that explosion; that, as a particular musical vibration will establish synchronous vibrations in particular bodies while it will not affect others, and as a chemical change may be wrought in a body by its interception of only particular waves of light, so some kinds of explosions or powerful vibratory impulses may exert a disturbing influence over the chemical equilibrium of certain bodies, resulting in their sudden disintegration, which other explosions, though developing equal or greater mechanical force, are powerless to exercise. Thus the mechanical force developed by the explosion of 3·25 grms. (50 grains) of chloride of nitrogen far exceeds that exerted by the explosion of 0·32 grm. (5 grains) of the strongly confined fulminates, yet, in their effects upon gun-cotton, the substances in question are not on an equality unless employed in about those proportions. It appears, therefore, that it is necessary to increase greatly the mechanical force of the explosion to obtain the desired result with chloride of nitrogen, in order to compensate for the deficiency or absence of some peculiar power possessed by the explosion of the fulminates. Again, in the case of nitroglycerine, we have a body which explodes with a development of force quite as great as that of the strongly confined fulminates, yet the detonation of gun-cotton could not be accomplished by the explosion in close contact with it of a quantity of nitroglycerine more than sixty-five times greater than the amount of mercuric or silver-fulminate required for that purpose. Do not these facts appear to demonstrate the existence of a remarkable difference in the *character* of the concussions or vibrations produced by exploding the two materials?

I venture to offer the following as being the most satisfactory explanation which occurs to me of the remarkable differences just pointed out in the behaviour of different explosive agents. The vibrations produced by a particular explosion, if synchronous with those which would result from the explosion of a neighbouring substance which is in a state of high chemical tension, will, by their tendency to develope those vibrations, either determine the explosion of that substance, or at any rate greatly aid the disturbing effect of mechanical force suddenly applied, while, in the case of another explosion which produces vibrations of different character, the mechanical force applied by its agency has to operate with little or no aid; greater force or a more powerful detonation must, therefore, be applied in the latter instance, if the explosion of the same substance is to be accomplished by it.

The power possessed by the violent explosion of a particular material (such as gun-cotton or nitroglycerine) to determine the apparently simultaneous explosion of perfectly separate masses of the same substance, does not excite surprise. Instances of the apparently simultaneous explosion of numerous distinct and even somewhat widely separated masses of explosive substances (such as simultaneous explosions in several distinct buildings at powder-mills) do not unfrequently occur, in which the generation of a disruptive impulse by the first or initiative explosion, which is communicated with extreme rapidity to contiguous masses of the same nature, appears much more likely to be the operating cause, than that the simultaneous explosion should be brought about by the direct operation of heat and mechanical force developed by the starting explosion. In submitting this proposition I confidently believe that I am not advancing a view which possesses any claim to novelty, but that I am only contributing some support, by the result of experiment, to an opinion which has been strongly entertained by many.

It appears remarkable that two substances so analogous as gun-cotton and nitroglycerine in their chemical constitution and general characters as explosive agents, should exhibit the very great differences which have been observed in their susceptibility to explosion by the effects of a detonation. An explosive mixture (such as percussion-cap composition) which will not detonate gun-cotton if used in considerable quantities and strongly confined, explodes nitroglycerine even if used in as small proportion as 0·2 grm. (3 grains); 0·32 grm. (5 grains) of the strongly confined fulminates is required to detonate gun-cotton, while 0·07 grm. (1 grain), and perhaps even less, will explode nitroglycerine. The detonation of gun-cotton by means of chloride of nitrogen can only be accomplished by employing about 3·25 grms. (50 grains) of that substance, while 0·1 grm. (1·5 grain) suffices for the explosion of nitroglycerine. It is obvious from these results that a comparatively very small amount of mechanical force, suddenly applied, suffices to develope the violent decomposition of nitroglycerine; it is therefore not difficult to understand why this substance, though incapable of detonating gun-cotton, even when used in considerable quantities, should be itself readily exploded by means of the latter. It was impossible to determine how small a proportion of gun-cotton would suffice for that purpose, because, in the necessary experiments, the gun-cotton would have to be placed in very close proximity to, or contact with, the nitroglycerine, in which case the fulminate-charge required for detonating the gun-cotton would alone much more than suffice for exploding the nitroglycerine.

The comparatively very great sensitiveness of this substance to explosion through the agency of a detonation may probably be ascribable in part to its physical character as a liquid, and in part to the fact that the proportion of oxygen to oxidizable elements is much more considerable in nitroglycerine than in gun-cotton.

In considering the manner in which a detonation operates in determining the violent explosion of gun-cotton and nitroglycerine in open air, I have, for the sake of simplicity, confined myself to an examination of the manner in which those particular explosive substances are affected by the disturbing agency in question. It must not, however, be supposed that the power to exert a violent explosive action, when unconfined or partly exposed to air, is limited to explosive *compounds*. A few experiments instituted with explosive *mixtures* (produced by the intimate incorporation of powerful oxidizing agents and readily oxidizable substances, the combustion of which furnishes gases or vapours) have demonstrated that the destructive or explosive force of these may also be fully developed under conditions most unfavourable to their operation as explosive agents, under ordinary circumstances, if they are submitted to the influence of *a detonation*. Mixtures of potassic chlorate with the sulphides of antimony or arsenic, with potassic ferro- or ferri-cyanide, with potassic picrate, and other explosive mixtures of similar nature, and lastly even gunpowder, have been readily made to explode, when unconfined, with the full force which they are capable of exerting, by being placed in contact with a confined charge of mercuric fulminate. As far as could be determined by small comparative experiments, the readiness with which the violent explosion of these mixtures can be developed is, as might be anticipated, in direct proportion to their sensitiveness to explosion by percussion. Thus a mixture of the potassic picrate and chlorate, freely exposed to air, is exploded apparently with as much facility as gun-cotton by the detonation of a small fulminate-charge, and the violence of the explosion approaches that of gun-cotton fired under the same conditions. The detonation of a freely exposed mixture of the chlorate with sulphide of antimony is somewhat less readily accomplished, and the violent explosion of gunpowder requires the fulfilment of special conditions favourable to the action of the detonating charge of fulminate. If the grains of a small charge of powder be merely heaped upon a flat surface, the case which contains the fulminate being inserted into the heap, they are simply scattered by the detonation of the fulminate; but if a corresponding quantity of gunpowder be so arranged that the dispersion of the grains is impeded (as by placing it in a cylinder quite open at the upper end), its violent explosion is accomplished with certainty.

The following experiment affords an illustration of the difference in effect between the ignition of gunpowder in the ordinary manner, and by detonation, under precisely similar conditions. A small iron cylinder (4 inches long, 0·15 inch thick, and 1 inch internal diameter, closed at one end) was inserted into heavy clay soil so that its opening was on a level with the surface, and the earth was firmly rammed round it. The cylinder was then filled with fine-grain gunpowder, into the centre of which an ordinary electric fuse (primed with meal powder) was inserted. When the latter was ignited, the powder exploded with a dull report, and the force was entirely directed upwards, no effect being produced upon the cylinder or upon its position in the ground. A second precisely similar cylinder, enveloped by earth in the same way, was filled with sand, into which was inserted an electric fuse primed with mercuric fulminate. The explosion of the buried fuse did not displace the cylinder, but had the effect of bulging it somewhat in the centre and cracking it slightly in one place. A third similar cylinder was filled with gunpowder, and an electric fuse primed with a corresponding quantity of fulminate to that used in the preceding experiment, was inserted, the mouth of the cylinder being left quite open, as in the other instances. The explosion of the powder was attended by a sharp report, the cylinder was rent into several pieces, which were scattered about, and a cavity was formed in the ground, the earth being projected to a considerable distance. The effect was, in fact, similar to what would have been produced had the powder-charge been in a buried and tightly closed shell. Similar results were obtained in other experiments, confirmatory of the power possessed by a detonation to develope the explosive force of gunpowder, under conditions antagonistic to the violent action of the latter under ordinary circumstances.

The results of a few experiments instituted with small charges of gunpowder (8 ozs. and 1 lb.) appeared to furnish decisive indications that their explosion through the agency of a detonation was considerably more rapid than when flame was applied tc their ignition under corresponding conditions. The charges were enclosed in sheet-tin cases closely resembling each other, and these were buried in the ground at depths of 18 inches in holes of corresponding dimensions, the earth being rammed down tightly upon the charges in the same manner, and by the same operator, in each instance. They contained electric fuses which, on the one hand, were primed in the ordinary way with meal powder, and, on the other, with mercuric fulminate. In the instance of the ordinary fuses, the explosion of the charges produced clear holes, the earth being partly piled up around, and partly scattered; but in the case of the charges fired with detonating fuses, much of the earth was thrown up vertically with considerable violence, but there was very little scattering effect, the hole being to a great extent filled up again by the earth momentarily displaced*.

That the explosion of gun-cotton through the agency of detonation exerts a more violently destructive action than its explosion when strongly confined, by the simple agency of heat, has been abundantly proved by blasting operations in various descriptions of rock, and by measurement of the comparative destructive effect of charges exploded under water. Charges of gun-cotton contained in blast-holes, and having a detonating fuse inserted in or placed immediately over them, have produced much greater rending and shattering effects in hard rock and in wood (although the blast-holes were left entirely open, or only filled with loose sand, earth, or powdered rock) than corresponding charges applied in similar positions, but fired with ordinary fuses, although in the latter instances the gun-cotton was confined by "tamping," or firmly closing the blast-hole to a considerable depth. A series of systematic experiments have been carried on at Chatham by the Government Committee on Floating Obstructions, with the view of comparing the destructive power of gunpowder and gun-cotton, in which charges of these materials were exploded in proximity to submerged targets, with systematic variations of the strength of the cases containing the charges, the depth of their immersion beneath the surface, and their distances from the targets. The results of these experiments warranted the conclusion that gun-cotton, when confined in cases of sufficient strength to develope its full explosive action, exerted a destructive effect equal to about five times that of gunpowder. A few experiments to compare with these have been recently instituted with charges of gun-cotton enclosed in thin sheet-metal cases and exploded by means of detonating fuses, and in these the destructive action upon vertical targets, placed at very considerable distances from the charges, was from ten to twelve times greater than that of gunpowder. The concussion imparted through the water to considerable distances, by the explosion of small charges (2 to 3 lb.) of gun-cotton in the new manner, very greatly exceeded in their effects the results produced by the explosion of submerged charges by the ordinary method.

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* The relative displacing powers of powder-charges fired under similar conditions by the two modes of ignition has since been made the subject of practical experiments at the Royal Engineer Establishment, Chatham (Nov. 1869).

A series of experiments has been instituted with the object of ascertaining whether the remarkable results obtained by exploding gun-cotton through the agency of a detonation were in any way ascribable to a peculiarity in the results of the metamorphosis. Known weights of gun-cotton have been exploded *in vacuo* by means of a small detonating fuse, and the volume of gas produced accurately determined. After deducting the volume furnished by the fuse employed, the results obtained corresponded very closely to those furnished by exploding shells, charged with gun-cotton, through the agency of a heated platinum-wire, under precisely similar conditions. The products of explosion of the detonated gun-cotton have been submitted to complete analysis, and the results (which will be given in detail in a memoir "On the Results of Explosion of Gun-cotton" which I hope shortly to submit to the Royal Society) did not differ in any very important respect from those obtained by the most complete metamorphosis of the substance when exploded in strong shells under ordinary conditions. As the chemical change sustained by the decomposition of gun-cotton, when exploded through the agency of a detonation, cannot be said to differ in completeness from that consequent upon a fulfilment of the ordinary conditions essential to the development of its full explosive force, the increased destructive effect developed by the explosion of gun-cotton through the agency of a detonation must obviously be ascribed to the greater rapidity of its explosion under these conditions. This conclusion appears to receive confirmation from some of the results of a series of practical blasting operations which I have recently conducted at Allenheads, in conjunction with THOMAS SOPWITH, M.A., F.R.S., from which it appeared that, while the splitting and shattering effects upon hard rock was much greater with "detonated" gun-cotton than with charges of this material exploded in the ordinary way, the displacement or projection of the broken rock appeared decidedly less considerable[*]. Again, the work accomplished in the way of displacement in a comparatively soft and yielding material, such as a very friable rock (*e. g.* chalk or soft limestone), is less considerable than when the more gradual explosion of gun-cotton is brought about by the usual mode of firing. In the case of the detonation of gun-cotton imbedded in such material, the force which is applied with comparative suddenness is to a considerable extent expended in the disintegration and compression of the surrounding material, before there is time for motion to be communicated through any considerable mass of the rock.

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[*] These results are borne out by recent experiments at Portsmouth upon the demolition of fortifications.—*November* 1869.

A further indication of the difference in the rapidity of explosion of gun-cotton by detonation and by the simple application of heat is furnished by the difference in the luminous effect observed in the two instances. The ordinary explosion of gun-cotton is attended by a considerable body of flame, due to the ignition of the generated carbonic oxide; but the detonation of gun-cotton is only attended by a sudden flash, which it is very difficult to observe in daylight if only small quantities are exploded. The transformation of the solid into gas appears, in fact, to be too sudden for the generated combustible gas to become inflamed.

In conclusion, it may not be out of place to refer briefly to a few illustrations of the important bearings which the new mode of developing the explosive force of gun-cotton has upon the practical uses of the material as a destructive agent. The confinement of a charge of gunpowder or gun-cotton in a blast-hole, by firmly closing up the latter with earth, powdered rock, or other compressible material (by the process known as tamping or stemming) to a depth greater than the line of least resistance opposed to the action of the charge, is essential to the success of a blasting operation; but the great rapidity of explosion, by detonation, of a charge of gun-cotton greatly reduces the value of this operation; the destructive effect of the material, when exploded in a hole which is left open, is not inferior in extent to that obtained by similarly exploding a charge confined in the usual manner. Thus the most dangerous operation in connexion with blasting may be entirely dispensed with*. In submarine operations, it is no longer necessary to enclose the charge of explosive agent in the strong and therefore cumbersome metal receptacles hitherto required to ensure the full development of its explosive force; the destructive action of a charge of gun-cotton, enclosed in a waterproof bag or thin glass vessel and exploded by detonation, being decidedly greater than that furnished by a corresponding charge confined in a strong iron vessel and exploded by flame. Small charges of gun-cotton simply resting upon the upper surfaces, or loosely inserted into natural cavities, of very large masses of the hardest description of rock or of iron, have broken these up as effectually as if corresponding charges had been firmly imbedded in the centre of the mass and exploded in the usual manner. Lastly, the certainty, facility, and expedition with which certain important military destructive operations may be accomplished by means of gun-cotton exploded by detonation, are not among the least important advantages which are now secured to this interesting and remarkable explosive agent.

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* This observation does not apply equally to large charges, such as are used in some military operations, for the placing of which it is necessary to sink or drive shafts or openings of large dimensions.

XV. *Description of the Cavern of Bruniquel, and its Organic Contents.*

By Professor Owen, *F.R.S. &c.*

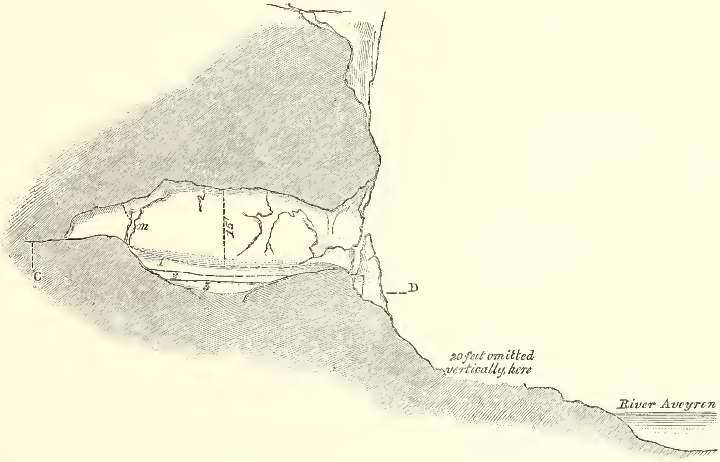
Received May 12,—Read June 9, 1864.

Part I.—HUMAN REMAINS.

The Cavern of Bruniquel, briefly noticed by Marcel de Serres in the subjoined passage from his work "Sur les Cavernes à Ossemens"*, is situated in a grand escarpment of the jurassic limestone bordering the river Aveyron, opposite the village of Bruniquel, Department of Tarn and Garonne.

The entry of the cavern is in the face of the cliff, about 40 feet above the bed of the river, partly concealed by a projecting peak of rock (fig. 1, d), behind which is a platform showing evidence of having been artificially flattened, so as to serve apparently as a stand-point for defence.

Fig. 1.



Vertical longitudinal section of Cavern of Bruniquel.

The entry (now bricked up, with a door in charge of a keeper of the proprietor, the

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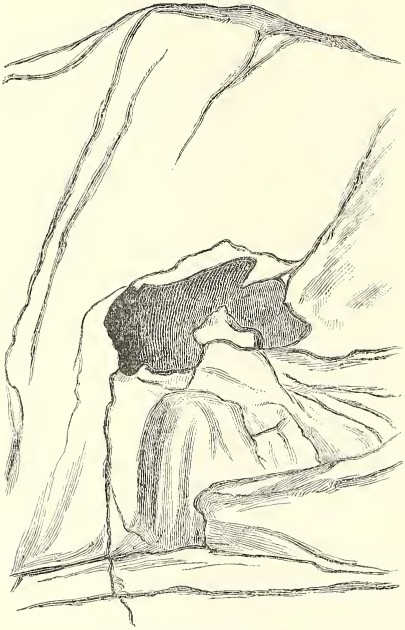
* "3° Caverne de Bruniquel (Tarn). Celle-ci paraît être dans la couche la plus inférieure de la formation jurassique, c'est-à-dire dans le lias. Nous n'y avons rencontré que des ossemens de ruminans, savoir des cerfs et de bœufs, avec quelques débris d'oiseaux."—*Op. cit.* p. 142. [See Note, p. 519.—R. O., July, 1869.]

Vicomte de Lastic St. Jal) is of an oblong form (fig. 2), about 20 feet in width, and from 8 to 12 feet in height; the cavern (fig. 4) widens a little beyond the entry, expanding to a breadth of about 50 feet two-thirds of the way towards the opposite end: the length of the cavern is between 60 and 70 feet; it has a pretty regular domed roof (fig. 3), and from the lowest part of the present excavated floor to the top is from 15 to 20 feet.

Fig. 2.



Entry of Cavern of Bruniquel.

The roof is evenly coated by a thin layer of stalactite, which now shows a few, and those but small, dependent processes; a larger columnar mass which reached to the floor near the back of the cave (fig. 1, *m*), had been removed before my visit (January 23rd, 1864). The original level of the peripheral part of the stalagmitic floor, was shown, at that date, by the adhesion to the wall of a portion projecting like a shelf, fig. 3, *s*, *s*, from 1 foot to 2½ feet in breadth, and averaging 1 foot in thickness, along about two-thirds of the circumference of the cavern. Upon this shelf the stalactitic coating of the cavern-wall is continued; the shelf of stalagmite slopes slightly from the wall to its broken margin. The breccia exposed by the breaking up of the stalagmitic floor slopes irregularly towards the middle of the fore part of the cavern, where the excavations have been carried deepest. Blocks of breccia covered by the stalagmite had been successively detached, prior to my visit, by the workmen employed by the Vicomte DE LASTIC; most of them had been broken up for the extraction of the organic and fabricated remains, and the débris thrown down the steep approach to the entry.

These researches had been commenced by the Vicomte DE LASTIC in the preceding year. Some excavations had been made many years previously, probably in quest of nitre during the old revolutionary period of 1792–5, and also subsequently, for scientific purposes, bringing to light the organic remains noticed by MARCEL DE SERRES. Of the extent of these early explorations I could not obtain any definite idea; no particular note of the floor of the cavern having been recorded when the systematic explorations were commenced, in 1863, by the Vicomte DE LASTIC*.

The appearances noted by me in the exploration of the cavern, January 23, 1864, led me to conclude that the original stalagmitic floor, compacted after the cave had ceased to be inhabited, had sloped gradually from the circumference to the centre or thereabouts, the stalagmite becoming thinner as it receded from the walls. There was nothing to support a conclusion that the different levels of the remaining stalagmitic floor at the periphery, and of the exposed breccia towards the middle of the cave, were due to any uplifting of the cliff, or change of level of the cavern, since the period of its habitation; all the phenomena observed concurred in showing the different levels to be the result of the excavations and removals of a great proportion of the original floor and of the immediately subjacent breccia.

This breccia is a conglomerate of mud, with water-worn stones from the bed of the adjacent river, chiefly of the grey limestone, and also of the reddish limestone, of which the cliffs are composed, with, occasionally, fragments of a quartzose rock. These are imbedded in and cemented to the petrified mud of a blackish or reddish colour, in many parts showing vacuities lined by stalagmite, and giving rise to a structure like that of travertin. Every part of such breccia is thickly charged with portions and fragments of bones, antlers, jaws, and teeth, implements of flint and bone, with here and there a shell; but these are very rare.

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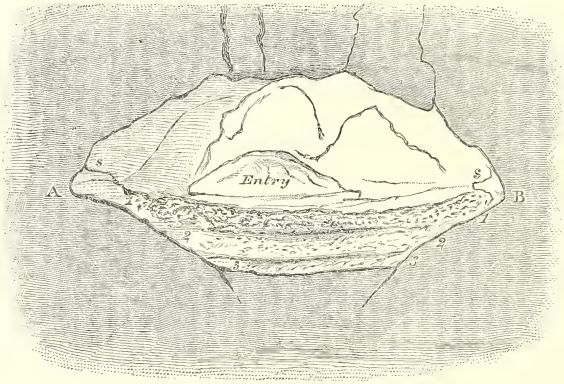
* [The reports of the discoveries made by the Vicomte DE LASTIC in his cavern led to visits being made to it by Naturalists and Archæologists from Toulouse and Montauban. MM. TRUTAT, MARTIN, and GARRIGOU communicated some results of their researches, December 10th, 1863, to the Académie Royale de Toulouse, but these have not been published. The earliest notice that I have been able to find, in print, is in the 'Bulletin de la Société d'Anthropologie de Paris' for 17th December 1863, in the form of an extract of a letter from M. GARRIGOU; it is headed "Découverte de deux mâchoires humaines dans la caverne de Bruniquel (Tarn et Garonne)." "Je suis rentré hier seulement d'une excursion dans le Tarn-et-Garonne, ou nous avons faites des fouilles considérables dans la caverne de Bruniquel," p. 651. That the cavern so called is the one here described I learnt from M. DE LASTIC, who caused the entry to the cavern to be secured in consequence of these and similar visits, attended with unauthorized removal of specimens. No other cavern so called was then, or had been previously, known in the vicinity of Bruniquel; it is therefore the cave noticed by MARCEL DE SERRES. The earliest notice in print that I can find of researches by M. BRUN, Keeper of the Museum at Montauban, in caverns in the vicinity of Bruniquel, is entitled, "Sur les fouilles pratiquées par M. BRUN dans la caverne-abri de Lafaye, in Bruniquel," in the 'Bulletin de la Société d'Anthropologie de Paris,' 18th Janvier, 1866. "La caverne-abri de Lafaye, fouillée avec le plus grand soin sous la direction de M. BRUN," &c.—*Op. cit.* p. 48. There is no evidence that the "caverne de Bruniquel," explored by MARCEL DE SERRES, the Vicomte DE LASTIC, and myself, has been known or described by any other name, or that its name has been applied to any other cave. It is the one nearest the village, though on the opposite bank of the Aveyron, and in the 'Commune de Penne.'—R. O. July 1869.]

The dark or black colour of the calcified or partly calcified mud or rubble, caused by particles of carbon indicative of the burnt fuel in the cavern, so prevails in the uppermost 4 or 5 feet of the breccia, that it is called by the workmen the "limon noir" (fig. 3_1). Beneath this the original reddish colour of the mud prevails, and a depth of from 3 to 4 feet has been reached in this so-called "limon rouge" (ib. $_2$). In both beds the organic contents abound; in the lowest part which has been reached (ib. $_3$) they become less abundant.

The major part of the soil of the cavern, broken up and removed at the period of my visit, had acquired a degree of hardness, through the percolation of the calciferous drip, such as to require short blows of the pick-axe for its disruption; it was of a density which, like that of the travertin at Pæstum, might have served for the purposes of a building stone. But towards the centre of the floor this density becomes less than towards the periphery, the breccia graduating into a kind of rubble.

The first human skull which was discovered, December 17th, 1863, was preserved in the mass of stalagmitic breccia in which it was imbedded and with which it was detached. The mass firmly adhered by the stalagmite to the wall of the cavern in the hindmost recess, to the left on entering, marked *a* in figure 4 (plan of horizontal section). The skull was about 4 feet below the upper horizontal surface or floor of stalagmite. This floor exhibited no signs of recent disturbance; the workmen were pursuing their operations to get out stalagmite and breccia in masses convenient for extracting and working out the organized contents and implements, when their attention was arrested

Fig. 3.



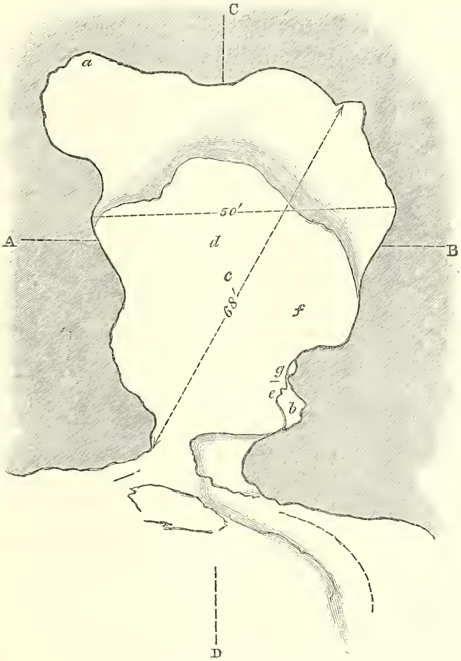
Vertical transverse section, Cavern of Bruniquel.

by the appearance of the cranium (as in the specimen now in the British Museum, Register-No. 38300).

M. de Lastic determined on its preservation in the breccia, for submission to anatomists and palæontologists for subsequent examination, and the block containing it was carefully removed from the cavern.

Similar operations being carried on at other parts of the cavern, an immense block of stalagmitic breccia became detached at the recess, marked *b* in fig. 4, and portions of two human crania became visible in the exposed surface of breccia adhering to the wall of the recess. The largest portion, including the calvarium (Register-No. 38307, British Museum), was situated 5 feet 2 inches from the upper surface of the stalagmite.

Fig. 4.



Horizontal section, Cavern of Bruniquel.

Like the hind part of the cranium above mentioned the more plastic material of the breccia, soft and moist at the period of the interment, had moulded itself to all the inequalities and contour of the surface of the calvarium, but with an interspace of from one to two lines in breadth, which was filled by pure stalagmite.

The portion of lower jaw, with the much worn tooth (Register-No. 38335, British

Museum), was extracted from breccia, at *e*, underlying the mass which yielded the calvarium.

The portions of upper and lower jaws (ib. 38334, 38337) were extracted from the less calcified breccia near the middle of the cavern, at about the depth of 4 feet at *d*, fig. 4.

The portions of upper and lower jaws (ib. 38336) with portions of cranium, were extracted from breccia at a depth of about 3 feet, at or near the position marked *f*, fig. 4 *.

The statement by the Vicomte DE LASTIC of the discovery of these human remains, in the letters of 24th December, 1863 and 4th January, 1864, addressed by him on the subject of his general collections derived from the cavern of Bruniquel, to the Trustees of the British Museum, determined me to avail myself of the liberty of action confided to me when those letters were referred to me by the Trustees. I proceeded at once to the Château de Salette to inspect the collection there in the possession of M. DE LASTIC, and soon afterward, 23rd January, 1864, visited Bruniquel in order to examine the cavern itself. The human crania discovered in the recess *b*, fig. 4, had been left *in situ* by M. DE LASTIC expressly for my examination.

The evidence of the former soft state of the earth or muddy part of the breccia, in its conformity with the superficial contour of the calvarium (Register-No. 38307, British Museum), was clearly shown. An unusual number of the large broad water-worn blocks or pieces of limestone had been piled, one above the other, for an extent of 3 feet above the crania, all firmly cemented together by intervening breccia, and suggested to me, what I stated at the time to M. DE LASTIC, that they had been placed over the crania for protection of the corpse or in a sepulchral relation thereto. Their numbers and arrangement called to mind a similar use of such stones accumulated at the places of interment of some of the ancient British, as, *e. g.*, that of the barrow on Balliden Moor, Derbyshire, figured in DAVIS and THURNHAM'S 'Crania Britannica'†.

In excavating beneath these crania several parts of the human skeleton were brought to light, in relative positions suggesting such a degree of dislocation as might be produced by the superincumbent mass of material subsiding and pressing upon the skeleton as

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[* The finding of human remains in the positions *d* and *f*, fig. 4, was fortunate and instructive. The mass of matter accumulated in a cavern undergoes slow change, affecting bulk, by the draining off of the water which held in solution the salts and in suspension the soil precipitated as mud: such shrinking of the consolidated and calcified mass tends, especially in a basin-shaped cavity like the Bruniquel-cavern, to withdraw the mass from part of the periphery of its containing basin. Into fissures so formed small objects, such as flint-knives or other weapons of the human inhabitants, are liable to slip and descend to some depth. But the fissure is gradually closed by stalagmite from the drip. Thus, indications of them may be detected at depths associated with remains of extinct animals, and a conclusion as to contemporaneity may be erroneously formed. Although there was no evidence of such marginal or peripheral fissures, due to natural causes such as are above referred to, having existed of width enough to admit a human skull, it was satisfactory to know that human remains were not exclusively met with at or near the periphery of the brecciated mass forming the floor of the cavern.—July 1869.]

† Part I. p. 45.

the soft parts decayed and were dissolved away, above which such mass had been heaped. The breccia including such bones was unusually hard and brittle.

In the shallow lateral recess, *g*, fig. 4, I discovered, at about 5 feet below the line or shelf of stalagmite, the portions of a human cranium (which are now readjusted in specimen, No. 38308, British Museum). The breccia adhered so firmly, by means of the intervening layer of stalagmitic matter, to the portion of frontal bone, as to bring away the outer table and expose the diploë and part of a frontal sinus in the attempt to detach this part of the skull (Register-No. 38310, British Museum). The care and pains requisite to detach the bone from the breccia can only be appreciated by those who have bestowed them in the attempt to overcome this most difficult part of the quest.

My interpretation of the layer of stalagmitic matter which intervenes between the bone itself and the mould of breccia, is, that the plastic breccia was moulded, soon after the interment of the coffin-less corpse, to the scalp and hair covering the calvarium; and that as these dissolved away their place was taken by the infiltrating calcareous material, which also lines for a certain thickness the interior of the crania (as shown in No. 38310).

In every part of the superincumbent breccia there were scattered implements of flint and bone, with bones or fragments of bones and antlers of the animals introduced by man into the cave for food.

The chemical constitution of the human remains, its correspondence with that of the other animal remains, the similarity of their relations to the surrounding breccia, the evidences of the plastic condition of the brecciated earth at the period of interment of the human bodies, all concurred in producing conviction in my mind of the contemporaneity of the foregoing human remains with the other organic contents of the cavern, and with the implements the application of which by man's hand to various purposess was abundantly and unmistakeably evidenced.

Under the conviction that the cavern of Bruniquel had yielded undoubted evidence of the bones of the human beings who inhabited the cavern at the period when flint and bone were the sole materials of their weapons and other implements, and when, as will be subsequently demonstrated, quadrupeds now extinct, and other quadrupeds now restricted to the extreme north of Europe, abounded in the South of France, I spared no pains to secure the collection for the British Museum; and, having succeeded, I have devoted such time as other duties permitted, in preparing the description of these human remains which I now submit to the Royal Society. Their interest consists in the high probability that they are the most ancient authentic specimens, hitherto discovered, which afford cranial and dental characteristics of the human race of such period*.

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* [Of the human remains in the sepulture at Aurignac, inferred by M. LARTET to have been contemporaneous with *Rhinoceros tichorhinus*, *Hyæna spelæa*, and *Elephas primigenius*, there were none attributable to an individual of large or even of middle size:—"Sur une dizaine d'os humains qui étaient restés engagés dans la terre meuble de la sépulture il n'y a aucun qui puisse être attribué à des sujets de taille grande ni même moyenne."—Bulletin de la Société Philomathique de Paris, Séance du 18 Mai, 1861. Apparently materials for charac-

I propose to submit to the Society a description of the other organic remains in future communications.

The portion of human skull remaining in the mass of breccia (Register-No. 38300, British Museum) consists of the hinder three-fourths of the cranium, including the occipital, parietal, and a great proportion of the sphenoid and temporal bones.

	inches.	lines.	inches.	lines*.
The extreme length of this portion of cranium is	6	6	6	1
The extreme breadth, outside the bases of the zygomatic arches	5	4	4	7
The extreme width of the cranial cavity	4	7	4	8
The extreme height of ditto	5	0	4	10

The foramen magnum measures 1 inch 9 lines in long diameter, 1 inch 3 lines in transverse diameter†. Its plane is nearly horizontal, as in other human skulls. The cranial cavity swells out 2 inches behind the posterior margin of the foramen.

The occipital condyles show the usual form and position. From the inner border of the left condyle to the outer border of the left mastoid process measures 2 inches 1 line. The mastoid presents the average development, indicative of the muscular forces concerned in balancing and moving the head in the ordinary erect posture of the human race. The pterygoid process is too delicate to allow of the thick incrustation of stalagmite to be removed, but it presents the usual length and other proportions.

The glenoid cavity and 'eminentia articularis' with the basal parts of the zygomatic arches exhibit precise conformity with the human type of these cranial features.

The thickness of the cranial walls, where fractured, across the fore part of the parietal and the temporal (squamosal) bones is not greater than that of the average European female skulls; it does not exceed two lines and a half at any part, and is from one to two lines thick at the major part of the circumference.

The interior of the cranium is lined by a thin layer of stalactite; the parts of the exterior in the angles between the stones, where the earth of the breccia had not come into contact with the bone, are coated with stalactite to a thickness, at some parts, of 4 lines.

Where the unbrecciated earth or mould has come in contact with the skull it is adapted to the inequalities of the surface, with the interposition above mentioned of a thin layer of stalagmite; and the earth has been hardened into breccia in that moulded

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terizing the race were not obtained. The major part of the human remains had been re-interred prior to M. Lartet's visit. Of the human mandible disinterred at Moulin-Quignon, near Abbeville, under the circumstances detailed by M. Boucher de Perthes, in the 'Compte Rendu de l'Académie des Sciences,' Paris, 20 Avril, 1863, p. 7, it would perhaps have been more to the interest and influence of science if one were not obliged to refer to 'Comptes Rendus de la Académie des Sciences,' Avril 20, 27, Mai 4, Mai 18, Mai 25, 'Times Newspaper' of 25th April, and other 'brochures' which appeared in 1863 on the subject of this doubtful fossil.—R. O., July 1869.]

[*] Negro skull, No. 96. See Owen, 'Skulls of Western Equatorial Africans,' figs. 7, 8, 9, pp. 12, 15, in Du Chaillu, Second Journey in Equatorial Africa, 8vo, 1867.

[†] In an Australian skull the foramen magnum has a circular form of 1 inch 4 lines diameter.

relation, precisely as we find the breccia and stalagmite in relation to the bones of the extinct quadrupeds and to the flint implements contained in the same mass.

Near the skull are some cervical and dorsal vertebræ, the former dislocated, some of the latter in natural juxtaposition with portions of the ribs. There is also the head of a femur closely adherent to the stalagmite moulded upon its articular surface, the rest of the bone having been broken away with the previously detached block of breccia, exposing the fine cancellous structure of the head of the femur.

The general arrangement, or rather disarrangement, of the fragments of the human skeleton in the present mass of breccia, suggests that the body had been originally interred in a sitting or crouching posture, and that after decomposition and dissolution of the soft parts, the skeleton had yielded to the superincumbent weight; the head having become detached for a short distance from the neck. Every appearance supports the inference that the human remains are contemporaneous with the other organic contents of the breccia.

This mass of breccia includes some of the flattened water-worn stones, of which many were introduced into the cavern, from the bed of the adjacent river, evidently for use as seats, anvils, fire-places, &c.; and from the greater number of such stones above the place where the human skulls were exposed in the recess of the cavern, marked *b*, fig. 4, I was led to infer that they had been thus placed to cover the interred body, or in some sepulchral relation therewith. There are many smaller irregular portions of stone in the mass; and the mud, in some parts of a brownish colour, in others blackish, is calcified or petrified by the infiltrating drip of the cavern.

The larger blocks of stone consist of the same kind of greyish limestone of which the greater part of the neighbouring rocks is composed. There is a reddish-coloured limestone in smaller fragments, which kind also appears, variegating the colour, in some parts of the cliffs. There is also a piece of micaceous schist about 4 inches diameter in the same mass of breccia.

I caused a cast to be taken of the interior of this hinder portion of cranium in elastic material, from which a mould was prepared affording casts in plaster of Paris, which convey an instructive idea of the size and form of the back part of the brain of the old cave-dweller.

The posterior lobes of the cerebrum are narrow but prominent, projecting beyond those of the cerebellum. The breadth of the cerebellum is 4 inches 1 line, the length of each lateral lobe is 2 inches 6 lines.

In extracting what appeared to be the more perfect of the two crania partially exposed in the recess *b*, fig. 4, the breccia was fractured with different parts of the cranium attached to the different pieces. The portions of cranium having been detached from the breccia were found on reunion to compose an almost entire 'calvarium' of one individual (Register No. 38308, British Museum). This, after the calcareous matrix had been entirely removed from both outer and inner surfaces, was soaked in a solution of gelatin to restore its original tenacity.

Although it does not include so large a proportion of the skull, it is more instructive in some respects than the preceding portion from the locality *a*, as it gives the length as well as the breadth of the cranial cavity.

It consists of the entire upper part or half of the cranial dome, usually termed the 'calvarium,' including the major part of the frontal, both parietal, and of the expanded superoccipital bones.

The following are admeasurements of the cranium afforded by this specimen, to which I append corresponding ones of a cast of the 'Engis skull,' which it resembles in shape though relatively shorter:—

	Bruniquel cranium.		Engis cranium*.	
	in.	lines.	in.	lines.
Extreme length, or antero-posterior diameter, at the outer surface	6	8	7	9
Extreme length, or antero-posterior diameter, at the inner surface	6	0		
Extreme breadth, or transverse diameter, at the outer surface . .	5	7	5	6
Extreme breadth, or transverse diameter, at the inner surface . .	5	2		
Length of the sagittal suture, following the curve	5	0	5	3

The broken margins of the calvarium show the varying thickness of the bones; at the frontal, which is broken away 2 inches 9 lines from the coronal suture, the bone is 4 lines in thickness, and gradually decreases to 2 lines and 1½ line in thickness as it approaches the parietal. The fractured margin of the parietal, near the frontal, and 3 inches in a straight line from the sagittal suture, shows a thickness of 3 lines, which decreases towards the lower border of the parietal (on the right side) to 1 line, with obliteration of the intervening diploë; at the middle of the parietal the thickness of the bone is 4½ lines.

The superoccipital is fractured about half an inch below the lateral sinuses, at the upper part of the cerebellar fossa, where the pressure of the cerebellar lobes within, and of the complexi muscles without, reduces the bone to a thin compact plate of ¼ of a line at some parts. The portion preserved has the shape of almost an equilateral triangle.

The superoccipital, above the 'superior curved line' or ridge, is rather more protuberant than usual, and shows the pair of convexities answering to the posterior cerebral lobes. The occipital tuberosity is not distinct from, or more prominent than, the transverse ridge of which it forms the middle part; below the ridge the superoccipital shows a concavity vertically, not divided by a vertical crest, of which only the beginning is indicated at the 'protuberance.'

The cerebral fossæ are well-marked smooth concavities on the inner surface of the superoccipital, the left, as usual, being the larger; and the superior longitudinal sinus descending to the right of the crest for the 'falx cerebri,' which divides the cerebral fossæ. The course of the lateral sinuses is marked by thick obtuse ridges diverging from the protuberance of the 'torcular Herophili,' and showing very slight excavation for the sinuses themselves.

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* Regarded by the experienced anthropologist 'PRUNER BEY' as exhibiting "le type celtique parfait."—Bulletin de la Société d'Anthropologie, 8vo, 1863, p. 305. Unfortunately, like the 'Neanderthal' skull, wanting the required demonstration of its antiquity.

The broadest part of the superoccipital here preserved measures in a straight line 4 inches. The parietals present the usual smoothness and convexity externally; the 'eminence' indicative of the commencing point of ossification is not distinctly marked; the temporal ridge or boundary is very feebly indicated. The venous 'parietal' foramen is larger on the left than on the right parietal; in both about 5 lines from the sagittal suture, and above 1½ inch from the lambdoidal one. The crenations of the sagittal suture are moderately developed externally, and are wanting internally. On the inner surface of the parietals the cerebral convolutions have left feeble impressions; the middle meningeal artery deeply grooves the anterior inferior part of the bone close to the coronal suture; posterior to this are less deep grooves for other branches of the meningeal arteries; the shallow depression for the superior longitudinal sinus is chiefly in the right parietal. The pacchionian depressions are few and feebly marked.

The part of the frontal bone preserved indicates it to be low and narrow; but its anterior part is broken away before the commencement of the 'frontal crest' leading to the 'foramen cæcum.' We have better evidence, therefore, of the want of breadth of the frontal than of the extent of the vertical part of the bone forming the forehead. I much regret having been unable to secure the superorbital ridge.

The fractured anterior margin of the frontal shows no trace of frontal sinus, but the bone is evidently broken away above those cavities. The greatest breadth of the frontal here preserved in a straight line is 4 inches 7 lines, that of the Engis skull is 4 inches 8 lines. The 'sulcus longitudinalis' is feebly marked. The crenations of the frontal suture are very minute as it extends from the sagittal suture until near the lower angle. The frontal eminences are not distinctly raised.

Upon the whole the proportions of the above-described calvarium are those of the longish oval, approaching to that which has been denominated the cymbicephalic or dolichocephalic type, *i. e.* 'boat-shaped' or 'long-shaped' cranium. It is broadest near and in advance of the junction of the middle and posterior thirds, whence it contracts rather rapidly backward, and with a slightly convex curve to the narrow prominent upper part of the triangular superoccipital which forms a stronger convexity, agreeing with the Celtic type, as exhibited by the Engis skull, and differing from the dolichocephalic form as exhibited by the Australian skulls, one of which I have selected to contrast with the calvarium from Bruniquel.

The following are dimensions of admeasurements above recorded of the Cavern-skull, as shown by the Australian cranium:—

	inches.	lines.
Extreme length, or antero-posterior diameter, at the outer surface .	7	7
Extreme length, or antero-posterior diameter, at the inner surface .	6	9
Extreme breadth, or transverse diameter, at the outer surface . .	5	4
Extreme breadth, or transverse diameter, at the inner surface . .	5	0

	inches.	lines.
Length of sagittal suture, following the curve	5	5
Breadth of superoccipital, in a straight line	3	9
Breadth of frontal, in a straight line	4	1

The cranium of the Australian contracts more at the frontal region, and slopes more from the sagittal tract; the parietal eminences are more distinct; the temporal ridges are more strongly marked; the texture of the cranial bones is more dense, but is not thicker than at the frontal region of the cavern-cranium.

Compared with an ancient Greek cranium, that from the cavern is less arched or elevated in the parietal and frontal regions, and is more convex in the superoccipital region.

The following are dimensions of the Greek cranium:—

	inches.	lines.
Extreme length, or antero-posterior diameter, at the outer surface	6	9
Extreme breadth, or transverse diameter ,, ,,	5	2
Length of sagittal suture, following the curve	5	0
Breadth of superoccipital in a straight line	3	9
,, frontal in a straight line	4	4

The only specimen that gives indication of the curve or convexity of the forehead is part of the left half of the frontal bone (Register-No. 38310, British Museum), from which a great part of the outer table has become detached, adhering to the breccia broken by the blows of the pick-axe which brought this evidence of human structure to light, in the recess *b*, fig. 4. One of the frontal sinuses has, by the same cause, been laid open.

The portion of the outer table remaining, shows the beginning of the external orbital process, but the form and degree of prominence of the superorbital ridge are not given. On the inner surface the frontal crest with the beginning of the ' sulcus longitudinalis is preserved.

The following are other portions of human crania obtained at from 4 to 5 feet in depth, from the recess *b*, No. 4.

A portion of the right parietal and a small contiguous portion of the superoccipital (Register-No. 38311, British Museum). A parietal foramen marks the contiguity of the border near which it is placed to the sagittal suture. The degree of convexity of the outer surface of the parietal, the non-indication of a parietal eminence, the convexity of the attached part of the superoccipital, the evidence of its triangular shape, the feeble indication of the temporal ridge, and the thickness of the bone are all characters in which the present fragment closely agrees with the more entire calvarium previously described.

A portion of the left parietal, including the parietal foramen, and the upper part of the middle meningeal artery (Register-No. 38321).

A portion of a parietal bone with the impression of a branch of the meningeal artery, showing a thickness of 4½ lines or 11 millimetres (Register-No. 38314, British Museum).

Part of the left parietal and frontal bones (Register-No. 38309, British Museum), showing thickening of the frontal and a similar low form of forehead to that in the calvarium (No. 38308). This portion shows part of a hole of about an inch in diameter, where so much of the bone appears to have been depressed or beveled off prior to interment. Two portions of left parietal bone, one with parts of the squamous and coronal sutures (Register-No. 38316, British Museum), the other with a parietal foramen (Register-No. 38317).

In a block of breccia from the same recess and depth was found the following portion of the lower jaw of an adult (Register No. 38335, British Museum).

The horizontal part of the left ramus with the symphysis retaining the first true molar, *m* 1, and the sockets of the two incisors, canine, two bicuspids and second true molar, of the same side: the socket of the third true molar, if it ever existed, has been obliterated, consequent on early loss of that tooth.

The sockets of the incisors are relatively smaller, especially in fore-and-aft diameter, than those in a female Australian; they more nearly accord in size with those of the European; the sockets of the premolars or bicuspids are simple, without the ridged indication of the grooved beginning of a division of the fang, as in the Australian. The socket of the second premolar is placed obliquely, and is divided, as usual, by a thicker septum from that of the first, than is the septum between any of the antecedent sockets. The first true molar is worn flat down to the stumps, sloping slightly from within outward and downward; a small part of the enamel is preserved on the inner ends, the friction, as usual, in human lower molars being greatest towards the outer margin of the crown; a smooth field of dentine composes the chief part of the grinding-surface: this molar is implanted, as usual, by two fangs, subcompressed from before backward.

The socket of the second true molar shows a similar insertion of that tooth, and that the anterior fang was grooved longitudinally at its fore part, and was larger than the posterior fang.

The fore part of the base of the coronoid process, which is preserved, shows the ridge extending to the back part of the last alveolar, and marking the boundary of the insertion of the temporal muscle. External to the ridge is the broad and shallow groove continued, contracting, along the outside of the hinder alveoli and bounded externally by the 'external oblique ridge' continued from the front margin of the coronoid process. The ridge subsides before reaching the 'mental foramen' here situated beneath the second premolar.

Beneath the foramen is a well-marked ridge for the origin of the 'depressor anguli oris' and for the insertion of the 'platysma myoïdes.' The symphysis developes anteriorly a well-marked 'mental process' or chin, the contour exemplifying a higher type than in the Australian; but the chin is of less vertical extent than in average-sized male jaws of Indo-european races.

Above the tubercular ridge at the back of the symphysis giving attachment to the genio-hyo-glossi muscles, is an unusually deep depression with a small foramen at the bottom: the ridge is not so distinctly divided into a pair of tubercles as in most human mandibles, nor is the second lower pair of tubercles marked, which give attachment to the genio-hyoid muscles. The sublingual depression is not well defined. The mylohyoidean ridge begins below the root of the second premolar, and has the usual course, rising obliquely to the inner and back part of the last alveolus. Above the ridge the inner surface of the jaw presents the usual smoothness, indicative of the vertical extent of reflection of the mucous membrane of the mouth, and it is rather convex vertically; below the ridge the surface is less smooth, and is convex vertically before bending to form the thick under-border of the mandible.

I have noticed in Australian skulls that the mylohyoid ridge is nearer the alveolar border of the mandible than in European skulls; showing that the mouth was less deep behind the large grinding-teeth, whilst the depression for the submaxillary gland was greater vertically. The cave-dweller resembles the European in the position and obliquity of the mylohyoid ridge.

In the less compacted breccia beyond the middle of the cavern at *d*, fig. 4, at a depth of about 4 feet from the surface, from which some portion had been removed during previous explorations, were discovered the upper (Register-No. 38334, British Museum) and lower (ib. 38337) jaws, and portions of the cranium of a child of about four or five years of age.

The deciduous dentition was in place and somewhat worn; the alveolus of the first true molar, *m* 1, intervened between the last deciduous molar, *d* 4, and the coronoid process of the lower jaw, and contained the calcified crown of that tooth, visible through the wide aperture of the formative socket which the gum had covered.

I have compared these remains with the skull of a child from an ancient Greek tomb, and with a skull of a child of the Murmi tribe inhabiting Nepal, both of about the same size and with the same phase of dentition as the Cavern remains.

The premaxillo-maxillary suture shows the same degree of obliteration as in the Greek child; more of the palatal portion is preserved in the Nepalese child; the intra-nasal portion of the suture persists, and the external portion is wanting, in each. The line of the front border of the premaxillary below the slightly prominent nasal spine is as vertical as in the Greek skull. The gubernacular orifice of the first incisor is the largest, that of the canine the smallest; the usual increase of thickness is shown in the septum dividing the alveoli of the canine and outer incisor.

The deciduous molars of the cavern-child strictly accord with the human type; the first of the upper jaw, *d* 3, has the two chief outer and inner risings of the crown with the notch near the posterior part of each. The second deciduous molar, *d* 4, is quadricuspid, with the antero-internal and postero-external cusps united by the oblique ridge: this tooth is rather larger in the cavern-child than in the Nepalese.

In the lower jaw of the cavern-child the ascending ramus is rather broader and lower than in the Nepalese; the chin is as well formed. The molar teeth closely conform, with the same degree of superiority of size in the second, *d* 4, of the cavern-child, and with rather more distinctness of the five tubercles, especially of the hindmost. In the position of the mental foramina and of all other characters of the mandibular bone the human type is closely preserved in the cavern-child. The condition of the bones, as to the degree of loss of gelatine, was the same as in the skulls of the adults.

Nearer the fore part of the cavern and to the right of the preceding locality, and at the same depth, were portions of the bones of an infant in a very fragile and far-gone condition, of which only the fore part of the lower jaw (Register-No. 38336, British Museum) and parts of a parietal, frontal, and superoccipital were extricated from the adherent breccia. The mandibular portion included the sockets of the incisors and canines, with those of the right deciduous molars. The first of these was emerging from the socket, as in an infant of about the tenth month; the apex of the deciduous canine had not pierced the gum; only the four inferior incisors had been in place. The mental prominence is well marked in this mandible; also the pair of fossæ behind the symphysis, for the geniohyoid muscles.

Whenever a sufficient number of skulls has been obtained from any given locality or country, or entombments of a period, the tendency of the brain-case to vary in its size, shape, and proportions to the face becomes manifest. This is exemplified in the 'Crania Britannica' of DAVIS and THURNHAM; in my own "Report on the Skulls of Natives of Nepal"*, and in the 'Crania Helvetica' of Professors HIS and RUTIMEYER. Among the figures in the latter work may be noticed both brachy- and dolicho-cephalic crania of the pre-Roman period, of the Roman period, and of the Burgundian period; even the few skulls obtained from the 'Pfahl-bauten,' or lake-dwellings, exhibit well-marked varieties. We learn, therefore, a wholesome distrust of generalizations as to the cranial characteristics of a particular race, or of the people of a particular period.

The calvarium from Bruniquel closely resembles in size and shape that from the Lake-dwelling at Mörigen-Steinberg, B VII; and also that from an ancient place of sepulture at Bolair. W. B VI. Like them it presents a good oval contour, and shows no mark or indication of an inferior or transitional type. The cerebral capacity is but small, is less than that of the skull from the Neanderthal cave, which in the development of the region of the frontal sinuses and superciliary ridge, closely resembles the old Batavian skull figured by BLUMENBACH in his last 'Decade,' No. LXIII.

The conclusions which I deduce from the examination of the foregoing facts of the human skeleton discovered in the Cavern of Bruniquel are as follows:—

They exemplify the distinctive characteristics of the human genus and species, as decidedly as do the corresponding parts of the present races.

They show most affinity with the oldest Celtic types, the cranium being oval, and rather dolicho- than brachy-cephalic in its general proportions.

The cranial capacity or brain corresponds with that of uneducated Europeans of Celtic origin; and exceeds that of the average Australian aboriginals.

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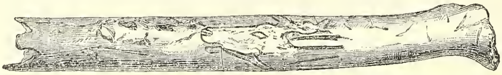
* Report on Skulls of various tribes inhabiting Nepal, British Association Report, 1859, p. 97.

From the paucity of human remains as contrasted with those of the lower animals in the cavern, it may be inferred that interment therein was exceptional. It might be reserved for the family of the chief of the tribe.

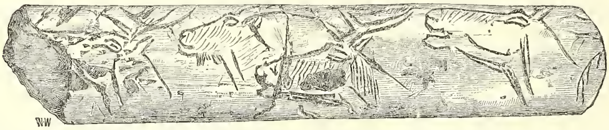
The specimens of ancient art figured in cuts 5 & 6 were detected by Vicomte DE LASTIC ST. JAL on removing the breccia from those implements in 1863, and were shown by the Vicomte to me on my first inspection of the Collection from the Cavern of Bruniquel, at the Château de Salette, January 22nd, 1864. They were afterwards shown by the Vicomte DE LASTIC to MM. MILNE-EDWARDS and LARTET on their visit of inspection at Salette, February 2nd, 1864, and are noticed by those gentlemen in the communication made to the Academy of Sciences, February 8th, 1864. (See the 'Compte Rendu' of that 'Séance' of the Academy.)

Fig. 5.



Portion of wing-bone of a bird with incised outlines of the head of Reindeer (*Cervus tarandus*); from the Cavern of Bruniquel.

Fig. 6.



Portion of rib of a Deer, with incised outlines of the heads of Reindeer and Bouquetin; from the Cavern of Bruniquel.

I subjoin a copy of the 'Letter' in which the name of the discoverer of outline drawings on bone by cave-dwellers of a 'Flint-period,' and the date of the determination of a species now extinct in the locality so inhabited, as a subject of such drawing, are given.

"Salette, January 24th, 1864.

"DEAR SIR,—I arrived at St. Antonin on Thursday evening, was met by Vicomte DE LASTIC and driven to the Château, where we arrived about 6 P.M.

"Friday, 22nd, was spent in examining the collection here. It is the most numerous, varied, and perfect series of the works in flint and bones of the earliest known human race that exists; it includes also a rich series of the remains of beasts and birds of the Cavern of Bruniquel from which the implements were obtained, and, above all, it contains the most unequivocal evidence of human bones, in conditions of imbedding demonstrative of their belonging to the earliest inhabited period of the cavern.

"In the present phase of research into Man's antiquity, and the general interest felt in that supreme question in his history, it is most important that these evidences be secured for the British Museum. Yesterday (23rd) I accompanied Vicomte DE LASTIC to the cavern itself, in his property at Bruniquel, which is about twenty miles from Salette, and explored that cavern and three other cave abodes of a more recent (bronze-age) date in the same grand escarpment or precipice of Jura limestone.

"In a recess of the cavern I saw a human cranium (the calvarium or upper part) *in situ*; a part of this had been exposed by M. DE LASTIC in his last visit, and he directed it to be left until my arrival: it was imbedded in the breccia about 4 feet below the level of the upper floor of stalagmite. Of the veritable original position in the firmly cemented mass of mud, hardened or petrified by infiltrated calcareous matter, with pebbles and water-worn stones, and here and there portions of Reindeer's bones, there was no room for doubt. The human remains in the Museum previously discovered are in a similar matrix; the precise positions where they were found were pointed out to me by workmen and the Vicomte. *Parts of the matrix show the moulding of the mud to the cranial dome before it became petrified.* There are remains of women and children as well as of men. The animal remains which I have hitherto determined belong to the large *Reindeer*, the *Red Deer*, gigantic *Ox*, a large *Horse*, *Fox*, and three kinds *of birds*, all (save Fox) seemingly introduced by the cave-dwellers for food (bones evidently broken for the marrow, &c.). The fragments of such bones are in heaps to be counted by thousands, and I may come upon other species of animals. M. DE LASTIC, since the first rough and unauthorized diggings by the Toulouse explorers, has walled up the entry to the cave, leaving a doorway in charge of his keeper. He has had three skilled diggers and cleaners of the remains at work with frequent superintendence by himself, carefully exhuming every tool and fossil; and the Museum here shows the result of that system. *Two implements exhibit an outline of an animal's head finely cut.* M. DE LASTIC pointed them out to me as of a Horse; but I discerned the Reindeer's profile and made out faint traces of the antler. *They are the earliest known works of graphic art representing a species now extinct in temperate Europe.* The perfection of the barbed instruments, of other various tools, of delicate needles, &c., is truly remarkable. Most of the specimens are in duplicate or multiples.

"The day was too far spent on Saturday to proceed with the extraction of the human calvarium and further exploration in that recess of the cave. On Tuesday, 26th, we shall again proceed to Bruniquel on this quest; I, however, exhumed with my own hands, on Saturday, bones and tools demonstrative of the conditions in which the previous acquisitions had been discovered and obtained by the Vicomte.

"Believe me, truly yours,

(Signed) "RICHARD OWEN."

"*To the Principal Librarian, British Museum.*"

"I certify the above to be a true copy from the letter (No. 970 of Letter-book, British Museum) of the date January 24th, 1864.

(Signed) "A. W. E. O'SHAUGHNESSY,
Assistant in the British Museum."

XVI. *Description of the Cavern of Bruniquel, and its Organic Contents.*

By Professor Owen, *F.R.S. &c.*

Received August 20, 1868,—Read January 7, 1869.

Part II.—EQUINE REMAINS.

With the remains of animals from the Cavern of Bruniquel I brought away evidences of about thirty individuals of the Horse-kind. Like those of other herbivorous quadrupeds, they consisted of broken-up parts of the skeleton, chiefly portions of jaws with teeth, fragments of the limb-bones, and detached teeth.

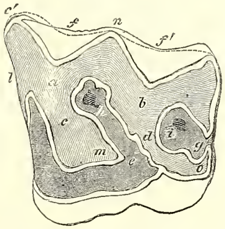
From the less instructive fragments left behind, or consigned to the rubbish-basket, I estimated that not fewer than a hundred individuals of the Equine genus had contributed to that proportion of the organic contents of the cavern which had been exhumed at the time of my exploration (January and February, 1864).

Of these, as of the other larger quadrupeds (*Bos primigenius*, &c.), the major part were of immature individuals—young colts and fillies; not more than four specimens of the entire molar series of permanent teeth (and I secured for the British Museum all such) had been extricated from the breccia and the hardened 'limon noir' and 'limon rouge' at the close of my second visit, February 1864. All these Equine remains were found mixed pell-mell with those of the other quadrupeds, owning no particular locality in the cavern, and at various depths from immediately beneath the then remaining thick marginal stalagmite (fig. 3, p. 520, *s s*) to a depth of 5 feet in the 'limon rouge' (ib. $_2$), about the middle of the cavern.

On a cursory comparison of the teeth, they indicated two kinds or varieties of Equines, slightly differing in size and in the relative size of the last molar tooth (Plate LVII. fig. 5; Plate LX. figs. 2–6).

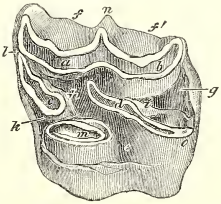
Before entering on the description of these fossils, I premise an explanation of the letters denoting the parts of the grinding-surface of the upper and lower molars in the accompanying Plates and Woodcuts (figs. 1–6), in order to abridge future remarks and facilitate the comprehension of the comparisons.

Fig. 1.



Upper molar, *Palæotherium.*

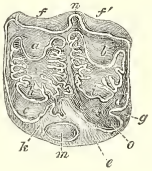
Fig. 2.



Upper molar, *Paloplotherium.*

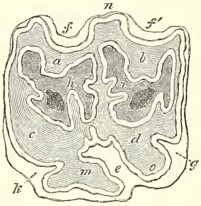
Upper Molars.—Cuvier, with his usual acumen, had detected beneath a general resemblance to the ruminant pattern in the Horse's grinders the more essential correspondence with that of the (perissodactyle) section of Ungulates to which the genus is essentially allied*. I here contrast an upper molar (*m* 1) of *Palæotherium* (fig. 1), of *Paloplotherium* (fig. 2), and of *Hipparion* (fig. 3) with that of *Equus*†, fig. 4.

Fig. 3.



Upper molar, *Hipparion.*

Fig. 4.



Section of upper molar, Horse (*Equus caballus*).

The longitudinal tract of dentine extending along the outer side of the crown ('colline longitudinale externe,' Cuv.) is partially divided by the two indents, *f*, *f'*, into an anterior, *a*, and posterior, *b*, lobe: the tract of dentine along the inner side of the crown is divided by an oblique fold or valley, *e*, into two lobes, *c*, *d*, extending obliquely backward from the outer tract, *a*, *b*, toward the inner side of the crown; these are the 'deux collines transversales' of Cuvier. Besides the fold, *e*, there is a shorter posterior one, *g*. These oblique folds or valleys are of more even depth in *Palæotherium* (fig. 1) than in *Rhinoceros* and *Equus* (fig. 4); they are so shallow, midway, in the latter, as to lead to an early separation of their respective beginnings or entries, *g* and *e*, from their terminations, *h* and *i*: the anterior oblique lobe, *c m*, is separated by the valley, *e h*, from the posterior oblique lobe *d o*; which is defined by the valley, *g i*, entering from the posterior side of the crown. The blind terminations of the two valleys, *h* and *i*, are more dilated, and their enamel-margin is more wavy, in *Hipparion* (fig. 3) and in *Equus* (fig. 4) than in *Palæotherium*, fig. 1; and, being soon cut off from the rest of the valley, in the wear of the equine tooth, they form the irregular crescentic islands, *h*, *i*, in figs. 3 & 4, leaving the entries of the valleys as shallow or short indents, *g*, *e*. The grinding-surface of the horse's tooth is made further complex by an indent, *k*, near the anterior internal angle, which, being nearly met by a fold of the main valley *e*, defines the accessory lobe *m*, just as the indent *g* less definitely marks a corresponding production, *o*, of the lobe *d*. Thus, in the upper molar of the Horse, fig. 4, we define the 'antexternal lobe,' *a*, the 'postexternal lobe,' *b*, the 'antoblique lobe,' *c*, the 'postoblique lobe,' *d*, and the 'internal lobule,' *m*; also the islands, anterior, *h*, and, posterior, *i*, which are the dilated and severed terminations of the antoblique, *e*, and postoblique, *g*, valleys; it becomes necessary to note also the anterior indent, *k*, and the lobular production, *o*.

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* "Les dents mâchelières supérieures de chevaux sont prismatiques comme celle de bœuf et de buffle, et marquées de même de quatre croissans."..."Au reste cette forme de couronne, tout en se rapprochant des ruminans, ne s'éloigne pas autant du rhinocéros qu'on pourrait le croire: elle peut aussi se réduire à une colline longitudinale externe et à deux collines transversales, qui envoient chacune un crochet en arrière."—*Recherches sur les Ossemens Fossiles*, Ed. 8vo, 1834, t. iii. pp. 202, 203.

† This comparison is given and illustrated in my 'British Fossil Mammalia,' 8vo, 1846, p. 384, figs. 126 & 143, and in Art. "Odontology," Encycl. Britan. vol. xvi. 1858. See also Rütimeyer, 'Beiträge zur Kenntniss der fossilen Pferde,' 8vo, 1863, tab. i.

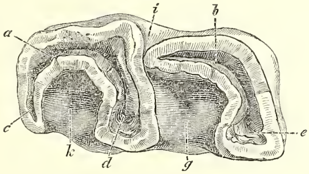
The genus *Paloplotherium* (fig. 2) manifests an instructive modification of the palæotherian upper molar surface approximative to that of *Equus*. The indent, *k*, is present and so deep that the accessory lobule, *m*, continues longer disconnected from the antoblique lobe, *c*, than in *Equus*; both the oblique valleys, *g* and *c*, are also deeper. What renders this modification of the upper eocene Palæotherioid the more interesting and suggestive is, that the Equine animal (*Hipparion*, fig. 3), of the succeeding (miocene) tertiary period, also long retains the accessory lobule, *m*, with its circle of enamel distinct.

Lower molars.—Save in Proboscidians and Tapiroids the lower grinders of Perissodactyles are divided into five lobes (fig. 5, and Plates LVII.–LIX.)—two outer, *a* and *b*, and three inner, *c*, *d*, *e*—by one external, *i*, and two internal enamel-folds or indents, *k* and *g*.

In *Palæotherium* the internal folds are simple and wide, reducing the inner lobes to the mere internal terminations of the two outer lobes which constitute the main part of the grinding-surface.

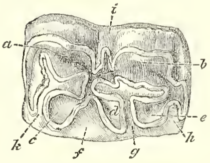
In *Rhinoceros* (fig. 5) the antinternal fold, *k*, resembles that in *Palæotherium*; but the postinternal fold, *g*, slightly expands as it penetrates the crown, and better defines the postinternal lobe, *e*: it is continuous with the outer fold, *i*, until the crown is partly worn down; prior to which there is an approach to the tapiroid or dilophodont type of grinding-surface.

Fig. 5.



Lower molar, *Rhinoceros*.

Fig. 6.



Lower molar, *Equus*.

In *Hipparion* and *Equus* (fig. 6) besides the antinternal fold, *k*, there is a midinternal fold, *f*, which is wide and shallow; the postinternal one, *g*, is narrow, deep, and expands abruptly at its termination, like *k*, in the fore-and-aft direction, after the pattern of the capital T. The antinternal fold, *k*, penetrating the fore part of the crown, dilates and runs along the same antero-posterior line as the terminal expansion of *g*, and divides the antinternal, *c*, from the antexternal lobe, *a*, just as the expansion of the fold, *g*, divides the lobes *d* and *e* from the lobe *b*. Finally, *Hipparion* shows short indents near the outer and inner parts of the back surface of the crown which define a small accessory hind lobule or 'talon.' In *Equus* (Plates LVII.–LIX. *m* 3) the greater development of this lobule, *l*, adds length to the working-surface of *m* 3—as the production of the lobe *a* in advance of the fold *k*, in *p* 2, makes that fold internal, as it is in *Rhinoceros* and *Palæotherium*, and adds length to the fore part of that grinder, producing it into a more or less acute angle.

Specific modifications.—Premising this definition and explanation of the parts of the grinding-surface of the upper and lower molars of the Equine dentition, there remains an obstacle in carrying out the comparisons of those characters in the Cave Equines with other extinct and existing kinds which has opposed all who have undertaken work analogous to the present.

To those, indeed, who may have access to specimens of the skulls and teeth of the known existing species of *Equidæ*, and to the teeth of defined fossil kinds, the difficulty is not felt in regard to the acquisition of personal conviction. But without, or away from, such opportunities of comparison, the help to be had from published figures of the dentition of Horses, Zebras, and Asses is very scanty, and of a kind inapplicable, or difficult and doubtful in its application.

Camper has given a side view, in his sketchy style, of the left side of the mandible of a young Zebra, with the deciduous molars *in situ*, and demonstrating, for the first time, the deciduous canine in any Equine (Œuvres de P. Camper, 1803, vol. ii. 8vo, pl. xxvi. fol. figs. 1, 4). In the plate the subject is reduced one-half, and the characters of the grinding-surface of the molars are wanting.

Cuvier has given a side view of the teeth *in situ* of *Equus caballus*, but reduced to one-fourth the natural size, in his 'Ossemens Fossiles,' 4to ed. 1822, p. 108, *Cheval*, pl. i. fig. 1. He has also given figures of the grinding-surface of the permanent teeth of the left side of the upper jaw of a horse (ib. *Cheval*, pl. ii. fig. 2), and of the right side of the lower jaw of a horse (ib. fig. 4). Similar figures of the deciduous dentition of a foal (*Poulain*) are added (ib. figs. 1 & 3, not figs. 1 & 2 as stated in the text, p. 105); but each of these figures is reduced to two-thirds of the natural size, and the surface of the grinders is little (if at all) abraded.

The text of Cuvier leaves us to infer that the figures in pl. ii. are of the Horse (*Cheval*, =*Equus caballus*); but the species is not more precisely denominated. Laurillard, in the posthumous edition of the 'Ossemens Fossiles,' does not give better information. In the description of the plates added to that edition, Planche 59, the reference is merely *Cheval*, plate ii. (Explication des Planches, p. 28).

I draw attention to this circumstance, because the comparisons which I have been led to make, and to illustrate by the accompanying drawings, between the different kinds of Equines have led me to suspect the possibility that the skull of an *E. asinus* may have been the subject from which the artist Huet drew the figures 2 and 4 of the plate *Cheval*, pl. ii. in the second volume of the 4to edition of the 'Ossemens Fossiles.'

The richly illustrated 'Ostéographie' of De Blainville does not supply what is really needful for the comparisons in question. The grinding-surface of the permanent dentition of *Equus caballus* is given in " *G. Equus*, pl. ii.," with outer and inner views of the teeth *in situ*; but these figures show the parts reduced to one-fourth the natural size. Side views of the skull and teeth of *Equus asinus*, *E. hemionus*, *E. quagga*, *E. zebra*, *E. Burchellii*, are also given at the same or a greater degree of reduction; but there are none of the grinding-surface. They are thus with difficulty and uncertainty, if at all, available in comparing the characteristics of the complex grinding-surface of the premolar and molar teeth in extinct and existing species.

Of the Equine teeth figured, of the natural size, in my 'History of British Fossil Mammals' (8vo, 1846), those from the upper jaw of *Equus caballus* are the working-surface of the third grinder, *p* 4 (*op. cit.*, fig. 142), and of the first grinder, *p* 2 (*op. cit.*, fig. 151): that from the lower jaw is of the third grinder, *p* 4 (*op. cit.*, fig. 144). From the upper jaw of *Equus fossilis* is figured the grinding-surface of *p* 4 * (*op. cit.*, fig. 143); and, from the lower jaw, that of *p* 4 (*op. cit.*, fig. 145†). Of the *Equus plicidens*, from the upper jaw, the working-surface of the first grinder, *p* 2, is given in fig. 152; and that of the second grinder, *p* 3, in fig. 153, p. 393, *op. cit.* Two upper molars of a small extinct species called *Asinus fossilis*, are given in figs. 157, 158, *op. cit.*‡

H. v. MEYER § gives figures, of the natural size, of some upper and lower teeth of *Hipparion*, and adds an outline figure of an upper molar of a recent *Equus* (tab. xxxii. fig. 34).

RÜTIMEYER, in his excellent 'Beiträge zur Kenntniss der fossilen Pferde,' &c., 8vo, 1863, has adhered to the rule of my 'History of British Fossil Mammalia,' and has given the figures of the grinding-surface of the teeth of the natural size. They include, of *Equus caballus*:—from the upper jaw, a premolar, tab. i. fig. 5, unworn, and fig. 9, worn, and fig. 11, a germ of a deciduous molar; from the lower jaw, tab. iii., a worn deciduous molar and one unworn, a premolar, *p* 2, a molar, *m'*, and three premolars, *p* 2, *p* 3, *p* 4, Taf. iv. fig. 45. Of *Equus fossilis*, Ow., are figured, *m* 1, *m* 2, *d* 2, 3, 4 of the upper jaw, and of the lower jaw a germ or unworn crown of *d* 4, the premolars *p* 2, *p* 3, *p* 4, also *m* 2. Of *Hipparion* are figured, the lower deciduous molars and the first molar, *m* 1, Taf. iii. figs. 28, 29; also the premolars *p* 2, *p* 3, *p* 4, and *m* 1, Taf. iv.

HENSEL, in his excellent account of the *Hipparion mediterraneum*, has given figures of the grinding-surface of the upper molars, Taf. iii., of that extinct Miocene species, which agree in generic character with the *Hip. gracile* from Eppelsheim.

In the comparison of fossil Equine molars the close general conformity of character of grinding-surface, which serves so easily and satisfactorily to determine the genus or family, leaves the closer approximation, as to species, to a comparison of the details of that complex type; and these details can only be satisfactorily contrasted, in the absence of the specimens themselves, by faithful figures, of the natural size, of the whole dental series of the several known species of *Equidæ*.

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* The minor breadth of the deciduous molars of this species, as represented by RÜTIMEYER, confirms the differential character of *Eq. fossilis* as deduced from this tooth, of which the figure is reproduced in a subsequent Paper, p. 567, fig. 1.

† This figure is reproduced, p. 570, fig. 4.

‡ This figure is reproduced, p. 567, fig. 2.

§ Beiträge zur Petrifaktenkunde (I. Fossile Pferdenartige Thiere, January, 1832); in 'Nova Acta Phys. Med. Akad. Naturæ Curiosorum,' &c. tom. xvi. pars post. 4to, 1833.

Such aid in the determination of the fossil teeth of the Horse-tribe, the want of which is greatly felt by palæontologists, I propose to supply, so far as the materials have been at my command; and I have caused carefully accurate drawings to be made, under my inspection, of the grinding- or working-surface of the permanent teeth of the following existing kinds of Equines:—

Equus caballus ♂, *E. asinus* ♂, *E. Burchelli* ♀, *E. zebra* (molar series, of nearly adult), *E. hemionus* ♂ (or Kiang), and *E. quagga* ♂.

Equus caballus.—The subjects of Plate LVII. figs. 1 & 2, are from a stallion of a nearly full-blood hunter, which stood 15½ hands high.

The series of upper molars have a very moderate degree of curvature, convex outwardly (Plate LVII. fig. 1, *p* 2 to *m* 3): the degree of convergence of the right and left series is shown in the reduced figure, Plate LXI. fig. 6, Phil. Trans. 1869, Part II. The first functional premolar (Plate LVII. fig. 1, *p* 2) has the grinding-surface anteriorly produced and pointed, *a'*; the last grinder, *m* 3, has the same surface contracted posteriorly, but less produced and ending more obtusely; its antero-posterior extent exceeds that of the contiguous molar, *m* 2, in a greater degree than in smaller varieties of *Eq. caballus* (see Table of Admeasurements, p. 552). In all the molars the outer longitudinal channels, *f*, *f'*, are broad and more or less flat at the bottom, the anterior one, *f*, being the deepest, the posterior one, *f'*, having the posterior boundary least defined; and that boundary is wanting in *m* 3. The intervening ridge, *n*, is rather broad, is flattened, and in the premolars is slightly indented or canaliculate. The lobes, *a*, *b*, are irregularly crescentic, with a slightly wavy enamel contour. The internal lobe, *m*, is oblong, antero-posteriorly produced both backward and forward, as at *p*; but, in this direction, least so in *p* 2, most so in *m* 3. It is represented by the circular summit of a detached column of enamelled dentine in *Hipparion* (cut, fig. 3, *m*). The hind end of *m* 3 is subbilobed. The length of the upper molar series is 7 inches 6 lines; the premolars forming rather more than half that extent.

The right and left series of upper grinders very slightly converge anteriorly. The interspace between the hindmost grinders is 3 inches 2 lines; that between the foremost is 2 inches 4 lines.

The series of the lower grinders (Plate LVII. fig. 2) is straight, equally divided between the false and true molars; the whole, as in other Ungulates, are narrower in proportion to their fore-and-aft breadth than the upper grinders, upon which they work as does the hammer upon the anvil; and they decrease in transverse thickness from the penultimate premolar (*p* 3) backward.

The outer longitudinal groove, *i*, indents the crown more deeply as the grinder recedes in position, at least from *p* 2 to *m* 2. The antinternal enamel-fold, *k*, bifurcates more completely than in *Hipparion*, the anterior prong being short and inclining outward;

the posterior prong extends backward along the anterior third of the grinding-surface. The mid internal fold, *f*, is deeper than in *Hipparion*. The postinternal fold, *g*, penetrates one-third the thickness of the crown, then extends pretty equally forward and backward, like the cross of the capital T; the forward production is longest in the two anterior, *p* 2, *p* 3, and shortest in the two posterior grinders, *m* 2, *m* 3. The hind lobule, *l*, decreases in transverse and increases in fore-and-aft extent from the second to the sixth grinders, in which it rather suddenly attains its maximum.

The above particulars are, in the main, rather generic than specific characters of the existing equine lower grinders; but the definition is requisite for carrying out subsequent comparisons, in which the specific marks of the molars of *Eq. caballus* will be made more apparent.

Equus asinus.—The subjects of Plate LVIII. figs. 1 & 2 are from a male Ass of the ordinary English domestic race and average size, about eight years old. In the upper series of grinders (fig. 1) the degree of oblique attrition of *p* 2 occasions the appearance of the working-surface of that tooth being more produced and acute anteriorly than it is in less worn and more evenly worn specimens. Besides the general inferiority of size of the teeth, that of *m* 3 is relatively less than in *E. caballus*, and it is not bilobed behind; the outer longitudinal channels, *f*, *f'*, are more evenly curved or concave; and, as the same character prevails in the inner enamel-wall of the lobes *a*, *b*, these are more regularly crescentic in shape. The longitudinal ridge, *n*, is relatively narrower; the posterior boundary of the channel, *f'*, is not produced in *m* 2 and *m* 3, and but feebly so in *m* 1. The lobule, *m*, has less antero-posterior extent than in the Horse. In the molars of a she-ass I find the inner margin of this lobe feebly indented near the middle*. A slight excess of fore-and-aft over transverse diameter of grinding-surface is recognizable in the Ass—such excess not being seen in the permanent grinders, *p* 3–*m* 2, of the Horse. The length of the upper molar series is 5 inches 10½ lines in the male, and 6 inches in one of the female Asses here examined: in the latter the interval between the right and left molars, *m* 3, is 2 inches 6 lines; between the right and left premolars, *p* 2, 1 inch 9 lines. The premolars form a greater share of the length of the grinding series than in the Horse.

In the lower molar series the relative inferiority of size of *m* 3, as compared with *E. caballus*, is also seen; and, as in the upper series, the three premolars occupy a larger extent of jaw compared with the three molars, than they do in *Eq. caballus*. The anterior fork of the fold *k* is more extended transversely toward the outer side of the crown.

Equus hemionus.—The subjects of Plate LVIII. figs. 3 & 4 are from a male Kiang (*Eq. hemionus*, Pallas?), from a skull ascribed to that species in GRAY and GERRARD's 'Catalogue of the Bones of Mammalia in the Collection of the British Museum,' 8vo, 1862, p. 274. The skull is marked '976, *h*,' and was transmitted from Nepal by B. H. HODGSON, Esq., H.E.I.C.'s Resident in that Province. It may have been received from Tibet. It is specifically identical with the skull, 976 *d*, from the North of Ladakh, Tibet, presented to the British Museum by the Earl of GIFFORD, as of the Kiang or 'Wild Horse' of Tibet, which is most probably the same species as the 'Dshiggetai,' or *Eq. hemionus*, from the Mongolian plains, described by PALLAS*.

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* I am indebted to Professor WORTLEY AXE, of the Royal Veterinary College, for the opportunity of comparing specimens of the Ass's dentition with those in the British Museum.

I do not find the grinding-surface of the teeth of this Equine anywhere figured; the outside view of the dentition in the much reduced profile of the skull in DE BLAINVILLE'S 'Ostéographie' (*G. Equus*, pl. ii.) is unavailable for such purpose and comparisons as the subject of the present Memoir requires.

The series of the upper grinders resembles that in the Ass, and differs from that in the Horse in the greater relative extent of the premolar part. The front grinder, *p* 2, terminates more obtusely; the last grinder, *m* 3, is relatively of less fore-and-aft breadth than in most horses, especially the larger varieties; it is less contracted behind than in the Ass; it is, in the Kiang here figured, subbilobed as in the Horse. The longitudinal channels, *f*, *f'*, are less concave than in the Ass, and resemble more those in the Horse; the intervening ridge, *n*, is narrower than in the Horse, but is indented in some of the teeth; the lobes, *a*, *b*, are less regularly crescentic than in the Ass. The lobule, *m*, in *p* 2, is more prominent in relation to its fore-and-aft extent than in Horse or Ass; but in the succeeding grinders this character is lost; the fore part, *p*, of the lobule, *m*, is more produced, more equal to the hind production, than in either Horse or Ass. The posterior fold or indent, *g*, in *m* 3, is deeper, and the general pattern of the grinding-surface of that tooth differs less from that of *m* 2 and *m* 1 than in Horse or Ass. The series of the upper molars, as in the Horse, is less curved than in the Ass. The length of the series is 6 inches 1 line; that of the series of lower grinders is 6 inches 2 lines. These teeth are relatively narrower transversely than in the Horse; the relative proportions of premolars to molars, in both jaws, is the same as in the Ass.

Equus quagga or *E. quaccha*.—The subjects of Plate LIX. figs. 1 & 2, are from the skull of a male Quagga in the British Museum, obtained from the Orange River, South Africa. The characters of the grinding-surface of the teeth are here, for the first time, figured of the natural size. The premolar part of the grinding series, like that in *Equus caballus*, is more nearly equal in longitudinal extent to the molar part, especially in the upper jaw, than it is in the Kiang or Ass; and this is due to the anterior grinder, *p* 2, being relatively shorter, and to the posterior one, *m* 3, being relatively longer antero-posteriorly, than in *E. hemionus* and *E. asinus*; but the last molar is more contracted posteriorly than in the Kiang, and is there more deeply bilobed.

In the upper molar series (fig. 1) the outer longitudinal channels resemble in shape those in the Horse; but the anterior one, *f*, is relatively wider in *p* 3 and *p* 4 than in the Horse or Ass. The lobule, *m p*, in *p* 3, is less thick from without inwards than in the Kiang, but is as short from before backwards, differing, with the Kiang, in this respect, from both Horse and Ass. In the succeeding grinders it gains slightly in antero-posterior breadth, and becomes flattened on the inner side and reduced in transverse thickness, and that to a degree greater than in Horse or Ass. The fore part of the upper grinding series bends inward more than in any of the foregoing Equines.

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* 'Novi Commentarii Academiæ Scientiarum Imp. Petropolitanæ,' t. xix. (1774), p. 394.

In the lower series of grinders (fig. 2) the outer longitudinal fold, *i*, is less complex than in the Ass, less deep than in the Kiang, still less so than in the Horse; the antinternal fold, *k*, is more complex, in *p* 2 and *p* 3, than in Horse, Ass, or Kiang. The terminal expansion of the fold *g* is wider, in the transverse direction of the tooth, than in the foregoing Equines. In the proportional extent of the premolars the Quagga agrees with the Kiang and Ass.

Equus Burchelli.—The subjects of Plate LIX. figs. 3 & 4, are from the skull of a full-grown female Dauw, from Caffraria, in the British Museum (No. 854 *a*).

On the right side of the upper jaw (fig. 3), the rudimental representative of *p* 1 in *Hipparion* and *Palæotherium* is retained, situated on the inner side of the anterior lobe or production of *p* 2, close to the fold *k**.

In the pattern and proportions of the upper molar series the Dauw closely resembles the Quagga. The grinding-surface of the last molar, *m* 3, has the well-marked bilobed termination: but the longitudinal channels, *f*, *f'*, of the antecedent grinders are more regularly concave, and the lobes *a*, *b* (in fig. 13, *p* 3) are more crescentic. The ridge *n*, as in the Kiang, Quagga, and Ass, is narrower, more simple, and more produced than in the Horse. The lobe *m*, in *m* 1 and *m* 2, is thicker transversely, and makes that side of the tooth more convex or prominent. The fore part of this lobe is less produced than in the Kiang.

In the lower molars (fig. 4) the terminal expansion of the fold *k* is less complicated with secondary foldings than in the Quagga, at least in *p* 3 and *p* 4, the Dauw in this particular resembling the Kiang and the Ass. The mid internal fold, *f*, is deeper and more angular than in the Kiang.

Equus zebra.—The drawing of the grinding-surface of the right upper molar series (Plate LX. fig. 1) is from the skull of a young full-grown male Zebra, from South Africa, in the British Museum (No. 706 *b*), showing a phase of dentition answering to that between the fourth and fifth year in the Horse. The last premolar, *p* 4, is just attaining the level of *p* 3 and *m* 1; the summits of the inner lobes, *c*, *d*, are beginning to be abraded, as are those those of their productions, *m*, *o*—the former showing the condition of the detached enamelled lobule which, by its longer retention of the insular character, is characteristic of the Hipparion's molars. The last molar, *m* 3, has cut the gum, but not reached the grinding-level. This tooth, so seen, presents a smaller relative size than in the Ass; but when abrasion and growth shall have brought a larger part of the crown to the grinding-surface, the proportion will be that shown in the Ass (Plate LVIII. fig. 1, *m* 3).

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* In my 'Odontography' this denticle is described as follows:—"The first deciduous molar is very minute, and is not succeeded, as in the Anoplothere, by a permanent premolar; yet remaining longer in place than the largest deciduous molars behind, it represents the first premolar, and completes the typical number of that division of the grinding series" (p. 572). Accordingly, to facilitate the comparisons with Hipparion, Palæotherium, and Anoplotherium, this denticle is marked *p* 1 in the Plates—a circumstance which has led to inference and comments which reference to the text would have shown to be groundless.

The antero-external angle in *p* 3 and *m* 2 is thicker and more indented than in the foregoing Equines. The lobule *m* is relatively smaller and less produced from before backward than in the Horse—the Zebra in this respect resembling the other striped Equines and the Asses, as it does in the greater antero-posterior extent of the grinder, compared with its breadth. The lower grinders of the Zebra show no differences from those of the Dauw worth figuring.

Some characters distinctive of *Equidæ* may be noted in the part of the jaw and teeth anterior to the grinders, the relative extent of this part to the molar series varying in different species. Thus, measured from the fore part of *p* 2 to the front margin of the incisor *i* 1, the extent in the upper jaw of the Horse equals *p* 2 to *m* 3 inclusive, less one-third of that molar (*m* 3); in the Kiang it equals *p* 2 to *m* 3, less two-thirds of *m* 3; in the Ass it equals *p* 2 to *m* 2 inclusive; in the Quagga it equals *p* 2 to *m* 2 inclusive, less one-third of *m* 2; in the Dauw it equals *p* 2 to *m* 2, less one-half of *m* 2. There is a corresponding difference in the relative extent of the diastema, from *p* 2 to the alveolar border of *i* 3, to the extent of the molar series; thus the diastema equals in the Horse *p* 2 to *m* 2 inclusive, less three-fifths of *m* 2; in the Kiang *p* 2 to *m* 1 inclusive, less one-eighth; in the Ass *p* 2 to *p* 4, less one-fifth; in the Quagga *p* 2 to *p* 4, less one-fourth; in the Dauw *p* 2 to *p* 4, less one-tenth.

Thus the relative extent of the diastema is greatest in the Horse, least in Quagga. The canine tooth is nearer the middle of the diastema in the upper jaw of the Horse than in the smaller Equines, especially the Ass.

The incisors appear to be relatively larger in the striped Equines than in the Ass, Kiang, and Horse.

Comparison of the teeth of Equus spelæus *with those of existing Equines.*

Having offered these preliminary remarks, with the requisite illustrations of the dentition of most of the existing species of *Equidæ*, I proceed to the comparisons of that of the Equines obtained from the Cavern of Bruniquel.

Provisionally, for convenience of reference, I designate them as belonging to an *Equus spelæus*.

Of the upper grinders of such Cave-Equines, from Bruniquel, the portions of jaws including the entire series of those teeth indicated two varieties, as above remarked.

The following were notable in a comparison of the first of them (Plate LX. fig. 2) with the corresponding part of the dentition of the Horse (*E. caballus*, Plate LVII. fig. 1). The specimen from the Cavern is the left upper jaw. The series of teeth therein (fig. 2) resembles the upper molar series of the Horse in the slight degree of curvature. The last molar, *m* 3, though not so large relatively as in the Horse's teeth figured, is not so small as in other recent Equines: it is as strongly bilobed behind as in *Eq. caballus.* The outer longitudinal ridge, *n*, is moderately thick and indented (in *p* 3). There is less inequality of extent between the false and true molars than in the striped Zebras and Asses. The inner lobule, *m*, is antero-posteriorly extended, chiefly backwards; it is not so thick transversely, not so prominent beyond the termination *o* of the lobe *d*, in *p* 3, as in the Horse. The external longitudinal channels are more regularly concave than in the Horse's jaw figured.

I am disposed to regard the affinities of this Cave-Equine, as indicated by the characters of the upper molar series, as nearer the *E. caballus* than the other existing species. It has belonged to a smaller variety than the present average-sized horses; suggesting an animal about the size of a Spanish genet, or a pony of 13½ hands high.

By reference to the Table of Admeasurements, p. 552, it will be seen that the molar series of the smaller variety of *Equus caballus* differs only by one line in longitudinal extent from that in Burchell's Zebra.

The specimen of this Zebra here compared is of a mare; and the same sexual condition may also relate to the size of the teeth in the Cave-Equine compared (Plate LX. fig. 2). The first grinder, *p* 2, in *Equus spelæus* has the anterior lobule, *a'*, shorter, and the internal lobule, *m*, a little longer, in proportion to its breadth, than in the Horse. The two outer ridges, *n*, *r*, are less prominent; the outer concavities, *f*, *f'*, are less deep; but these may relate to the greater degree of attrition of the crown in the Cave-species. In the four succeeding molars, the inner lobule, *m*, in *Equus spelæus*, shows a longer and more angular grinding-surface, *i. e.* the fore-and-aft diameter of this surface is proportionally greater, *e. g.* than in the *E. Burchelli.* This diameter prevails over the transverse one in *m* 2 and *m* 3. The grinding-surface of *m* 3 is rather longer in *Equus spelæus* than in *Equus Burchelli*, and chiefly through the greater extension backward of the two posterior lobes; the transverse breadth of the tooth is not increased in the same proportion.

The upper molar series of the second variety of Cave-Equine (Plate LX. fig. 3) indicates a larger animal than the preceding. The disposition of the series of teeth presents a greater curvature, in this respect resembling the Zebra (Plate LX. fig. 1), a resemblance which is repeated in the shape and relative size of the last molar, *m* 3. But in the proportions and configuration of the premolars the present Cave-fossil very closely agrees with *Equus caballus* (Plate LVII. fig. 1). The ridge, *n*, and grooves, *f*, *f'*, in *p* 3, closely adhere to the pattern shown in the same tooth of the Horse (Cut, fig. 4). In *p* 4 the ridge becomes less flattened, and the channels more regularly curved. In *m* 1 and *m* 2 of the Cave-Equine the postero-external channel, *f'*, wants the boundary given by the outward production of the postexternal angle of the tooth in *E. caballus* (Plate LVII. fig. 1, *m* 1, *m* 2); the lobule *m* is more deeply impressed on the inner side. But the chief distinction is in the minor proportions and more simple structure of the hinder half of *m* 3.

Compared with the Ass (Plate LVIII. fig. 1) the molar series of *Equus spelæus* (Plate LX. fig. 3) shows the larger size of the latter animal, and also the greater antero-posterior extent of the lobule *m*. The non-extension outward of the postexternal angles of *m* 1 and *m* 2, and the form and proportions of *m* 3, are the points of agreement of the Ass with the spelæan Equine.

The molar series of *Equus spelæus* (Plate LX. fig. 3) bespeaks a larger animal than the Kiang (*E. hemionus*, Plate LVIII. fig. 3). The series is more curved in this Cave-horse. The anterior grinder (*p* 2) is more produced and ends (or begins) more acutely (at *a*'); it is more like that of *Equus caballus* both in dimensions and in pattern. In the shape and relatively larger size of the lobule *m* of *p* 2, the spelæan Equine also resembles the Horse more than the Kiang. The last grinder, *m* 3, has the same relative smallness as in the Kiang, but terminates more acutely, the dentinal lobe, *d*, not being extended backward so as to give the bilobed termination shown in the Kiang and the smaller variety of Cave-Equines. The narrower posterior surface of *m* 1 and *m* 2, due to the non-production outward of the postexternal angle, is a character common to the *Equus spelæus* and *E. hemionus*.

In the Quagga (Plate LIX. fig. 1) the difference in transverse extent of the fore and hind surfaces of *m* 1 and *m* 2 is rather less than in *Equus spelæus* (Plate LX. fig. 3). In this respect, as in the bilobed termination of *m* 3, the molar series of the *Equus spelæus*, var. A (fig. 2, Plate LX.), more resembles that of the Quagga. *E. spelæus*, var. B (Plate LX. fig. 3), shows the same superiority of size to the Quagga as to the Kiang and Zebra, and the same closer resemblance to the Horse in the proportions and pattern of the premolar teeth, and of the lobule *m* of all the grinders. The same observations apply to the comparison of Plate LX. fig. 3 with Plate LIX. fig. 3, *Equus Burchelli*. In the comparison of the upper molar series of the variety B of *Equus spelæus* (Plate LX. fig. 3) with that of *Equus Burchelli* (Plate LIX. fig. 3), besides the greater size of the teeth, there is a difference in the minor extension of the anterior lobule of *p* 2 of the Cave-Equine—the inner enamel-wall of which is continuous to the apex of the lobule, without the indent which marks off the base of that lobule in *Equus Burchelli*; this enamel-wall meets that extended from the outer and anterior ridge, *r*, at almost a right angle in *Eq. spelæus*, var. B, yet forming a less-obtuse point than in var. A, or in *Equus Burchelli*.

The enamel-wall of the valley *e*, *p* 2, makes a retroflex bend at its closed end in *Equus spelæus*, var. B, not present in the Dauw, the Zebra, or the Quagga, nor in *Equus spelæus*, var. A. It is usually present in the Horse.

The inner lobule, *m*, of *p* 3 to *m* 2, in *Equus spelæus*, var. B, has a grinding-surface in which the fore-and-aft extent is greater relatively to the transverse one than in *Equus Burchelli* and *E. Zebra*. In this character both varieties of the spelæan Equine resemble more the Horse than the striped species or the Asses.

The portion of mandible or lower jaw affording the view of the entire series of grinders of the *Equus spelæus*, the subject of fig. 5, Plate LVII., could not be referred (from original juxtaposition in the Cave) to either of the series of the upper grinders from the Bruniquel deposits. But, as the series bears the same proportion in length to the upper molar series of *Equus spelæus*, var. B (Plate LX. fig. 3), which the upper and lower series of grinders show in *Equus caballus*, *E. hemionus*, *E. asinus*, &c., it may be concluded that the subject of fig. 5, Plate LVII. belonged to the same variety, or came from an individual of the same size, as the subject of Plate LX. fig. 3.

Consequently this series of lower grinders of *E. spelæus* shows the same degree of inferiority of size to that of the large Horse figured in Plate LVII. fig. 2, as is exemplified by the upper molar series; but the resemblance in the essential characters of the grinding pattern, and in the proportions of the individual teeth, is very close. The expansion of the postinternal enamel-fold, *g*, of *p* 2 and *p* 3, is more wavy in *E. spelæus*; but this character is not repeated in the succeeding grinders. The antero-posterior extent of the premolars and of the molars is equal, as it is in *E. caballus*; in the other existing Equines the premolars occupy a greater longitudinal extent than do the molars. The last molar, *m* 3, is narrower transversely, and terminates more acutely than in *E. caballus.* In comparison with the Kiang (Plate LVIII. fig. 4) the lobe *d* of *p* 4–*m* 2 is more compressed and produced, the expansion of the fold *g* is wider in all the grinders, and the terminal lobe, *l*, of *m* 3 is larger in *E. spelæus.* The same remarks apply in the comparison with *E. asinus* (Plate LVIII. fig. 2). In *E. quagga* (Plate LIX. fig. 2) the terminal expansion of *g* resembles in width that in *E. spelæus*, and the lobe *l* of *m* 3, comes nearer in its proportions to that in *E. spelæus.* In the Dauw (Plate LIX. fig. 4) the transverse dimensions of the lower grinders are more equal, do not decrease so regularly or uniformly from *p* 3 backward as in *E. spelæus.*

Upon the whole, from the characters of the lower grinders, I incline to regard the Cave-Equine as belonging rather to the section of true horses than to that of the striped or asinine species.

In the Ass and Kiang the lower canine, in the male, is relatively closer to the incisors than in the Horse (comp. Plate LVIII. figs. 2 & 4 *c* with Plate LVII. fig. 2 *c*); in the Quagga (Plate LIX. fig. 2) the interval between *c* and *i* 3 is about the same as in the Horse.

An entire lower jaw of a fossil Equine from Newer Pliocene deposits at the "Tour de Juvillac" of the river Allier, Puy-de-Dôme (Plate LVII. fig. 6), shows the same relative position of the canine as in *E. caballus.* But this fossil accords so closely in dimensions and in the pattern of the grinding-surface of the teeth with the *E. spelæus*, that I believe it to be of the same race of horses.

The slight difference in the minor relative size of *m* 3 (Plate LVII. fig. 6) is due to the state of attrition of the teeth of the specimen figured, which are from an old horse with the mark entirely worn away from the incisors *i* 1–3. Allowing for the difference of size and age of the individuals supplying the specimens (Plate LVII. figs. 2 & 6), the length of the diastema between *p* 2 and *c* is the same, as is that between *p* 2 and the socket of *i* 3; there is a like correspondence in the length of the symphysis mandibulæ.

The age of the animal whose remains have been obtained from sedimentary freshwater deposits, and the age of the animal from the Cavern, indicate the different circumstances under which they have respectively died—the one probably from old age, the other by the hand of man.

Neither the text (pp. 155, 156) nor the figures (plate iii. Pachydermes) relative to the remains of Equines, in the 'Recherches sur les Ossemens Fossiles du Puy-de-Dôme,' by Croizet and Jobert, 4to, 1828, allow of further deductions beyond the fact that they relate to a species of the size of *Equus spelæus*, and, like it, more resembling the Horse than the Ass*.

In the collection of Equine fossils from freshwater beds at the "Tour de Juvillac" (alluvion supérieur of Bravard's MS. Catal.) are two series of grinders, each from the left side of the upper jaw, one agreeing in size with those of var. A of *Equus spelæus*, the other with those of var. B. But the smaller series has the last molar, *m* 3, less bilobed behind than in var. A (Plate LX. fig. 2, *m* 3); it more resembles that in var. B (fig. 3, *m* 3). The series of the smaller grinders of the Puy-de-Dôme Equine are in a less straight line than in Plate LX. fig. 2, their curve agreeing with that of var. B, Plate LX. fig. 3. For the rest, the correspondence of the series of molars from the Auvergne beds (No. 34657 of Register, Brit. Mus.) with that of the Cave-Equine (Plate LX. fig. 2) is so close as to leave no doubt as to their specific and racial identity. The same conclusion is enforced by a comparison of the series of molars of larger size from the Auvergne beds (No. 34658 of Register) with the series of var. B from the Bruniquel Cavern (Plate LX. fig. 3). In both instances the evidence of similarity, under the slight difference of size, is such as to impress one with a conviction that such difference relates to variety of size or difference of sex, rather than to race or species.

Comparison of the teeth of Equus spelæus *with those of other fossil Equines.*

The upper molars of *Equus spelæus* differ from those of *Equus fossilis*, Ow.†, from the Oreston limestone fissures, in the greater transverse breadth of the crown as compared with the fore-and-aft diameter (comp. *p* 4, fig. 3, Plate LX. with fig. 143, *op. cit.*). Like the molars of the recent *E. caballus*, those of *E. spelæus* are more quadrate in transverse section, less narrow transversely. The lobule *m* is broader transversely, and the ridge, *n*, is thicker.

The lower molars of *E. spelæus* (Plate LVII. fig. 5, *p* 4) show the same difference from the fossil ones from the Oreston Cave-fissures (fig. 145, *op. cit.*), viz. in the greater relative transverse breadth, agreeing in this respect with the lower molars of the existing horse.

Not any of the fossil Equine teeth from Bruniquel show the degree of plication and the thinness of the enamel-folds which characterize the *Equus plicidens* from Oreston* and from Newborne, North Carolina†.

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* All the Equine fossils from upper pliocene beds at Malbattu, Puy-de-Dôme, are referred "à une seule espèce dont la taille approche de celle des zèbres et des grands ânes" (Croizet and Jobert, *op. cit.* p. 155).

† Brit. Foss. Mam. p. 383, fig. 143. The last milk-molar, *d* 4, of this extinct species figured by Rütimeyer (*op. cit.* tab. i. fig. 12, D 1) is 32 millimetres in fore-and-aft diameter, 20 millimetres from the outer middle ridge to the inner part of the lobule *m*. Its successor, the last premolar, *p* 4, figured in 'Brit. Foss. Mammals,' fig. 143, has the same fore-and-aft diameter, with an increase of breadth of 5 millimetres, across the same part of the grinding-surface; Rütimeyer's figures, *op. cit.* tab. i. 7, 8, 10, are true molars of *E. fossilis*, Ow.; fig. 6 is a permanent molar of another species more nearly allied (if not belonging) to *Equus caballus*.

The inner enamel-folds of the upper grinders of var. B of *Equus spelæus* are more wavy than those in var. A; but if the first upper grinder, *p* 2, of *Equus spelæus*, var. B (Plate LX. fig. 3), be compared with that tooth of *Equus plicidens* ('British Fossil Mammals,' p. 392, fig. 152), it will be seen that, besides the thicker and less plicate enamel of *E. spelæus*, the crown is longer, and more acute anteriorly, in the Bruniquel Equine. The differences presented by the fossil Equines of America will be noticed in a subsequent paper; those which are seen in the Asiatic and European Miocene Horses (*Hipparion*, Cut, fig. 3) are still more decisive.

Amongst the less complete specimens of Equine jaws and teeth from the Cave of Bruniquel a few were found which illustrated phases of dentition, and lend further help in tracing out the affinities of the species. The subject of Plate LX. fig. 4 is the grinding surface of the last four molars, left side, upper jaw, of a young animal, with the first and second true molars, *m* 1, *m* 2, abraded by mastication, and with the last premolar, *p* 4, and last molar, *m* 3, not yet in place. This phase of dentition is almost identical with that shown by the Zebra (Plate LX. fig. 1). But there the summits of the inner lobes of *p* 4 have began to show attrition; whilst in the Cave-Equine the antero-internal lobe of *m* 3 has just been touched, and no part of *p* 4 shows any action of the opposing tooth. Occasionally, in *Equus caballus*, the last molar a little precedes the last premolar in coming into action. At the phase of development shown in Plate LX. figs. 1 & 4, the analogy of the immature grinder, *p* 4, to the fully developed one in the palæontologically earlier Equine (*Hipparion*) is interestingly exemplified. The inner lobule, *m*, is a column detached at the summit, which when abraded, as in Plate LX. fig. 1, *p* 4, shows an island of dentine girt by enamel, as in the corresponding, but older and more worn, tooth of *Hipparion*. The earlier confluence of the column with the body of the tooth in *Equus*, occasions the earlier conversion in the course of attrition of the island into a peninsula, as in *m* 1 & *m* 2 of figs. 1 & 4. The later confluence of the column, or the maintenance of its distinctness nearer to the base, occasions the longer retention of the insular figure of *m* in the upper molars of *Hipparion*; but in old or much-worn grinders of this genus it also shows continuity of dentine with the lobe *c*.

The young *Equus spelæus* differs from the young Zebra in the greater relative size of the column *m*, leading to the corresponding greater antero-posterior and transverse diameters of the lobe *m* when worn into union with the rest of the tooth, as in Plate LX. fig. 3, *p* 4.

The nearer affinity to *Equus caballus* is likewise shown by the larger size of the first and second molars (*m* 1, *m* 2, fig. 4). But the last molar retains, in the present young spelæan Equine, the small relative size distinguishing all its kind from the larger variety, at least, of the modern *Equus caballus*. The size of *m* 1 and *m* 2 in Plate LX. fig. 4 accords with that of *m* 1 and *m* 2 in fig. 3, as does also the plication of the inner enamel, and the form of *m* 3, as indicated by the germ in fig. 4, *m* 3. But at the stage of attrition of *m* 1 and *m* 2 in the young animal the proportion of length to breadth of the grinding-surface is nearer that in those teeth of fig. 2, Plate LX.

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* Brit. Foss. Mam. p. 392, figs. 152, 153.

† Leidy, Proc. Amer. Acad. of Sci. Philadelphia, September, 1847, p. 262.

Most of the Equine fossils from the Cave of Bruniquel are from young individuals. In Plate LX. fig. 5, is figured a fragment of the left upper jaw, with the first permanent grinder, *p* 2, about to cut the gum; the less-advanced second, *p* 3, and third, *p* 4, premolars had not displaced the corresponding deciduous teeth, *d* 3, *d* 4, which had been worn nearly to the much absorbed stumps. This phase of dentition corresponds with that of a colt of *Equus caballus* between two years and two years and a half old. The upper deciduous molars, *d* 3, *d* 4, of *Eq. spelæus* (fig. 6, Plate LX.) differ from those of the Zebra and Ass, not only in their larger size, but in their greater breadth transversely, relatively to their length of grinding-surface, albeit they show the degree of narrowness which characterizes the milk-molars in *Equus caballus* (Plate LVII. fig. 3). The lobule *m* is relatively larger and broader from without inward.

In the subject of Plate LVII. fig. 7, the first lower permanent grinder, *p* 2, has come into place and has been worn sufficiently to expose the characteristic markings of its grinding-surface. The correspondence of the pattern to that in the more worn homologue of the mature Cave-Equine (Plate LVII. fig. 5, *p* 2) is instructively close. The anterior division of the terminal expansion of the fold *g* shows the same crenation of the outer enamel-wall; the fold *k* has the same simple bifurcation. The correspondence is instructively close, also, with *p* 2 in Plate LVII. fig. 6. The permanent mid incisors, *i* 1, fig. 7, have displaced their deciduous predecessors, and have been worn down to the 'mark.' The contiguous permanent incisors, *i* 2, are just appearing above the alveoli, and the summits of the permanent canines, *c*, are visible. This state of dentition indicates a young stallion, or colt, of about three years. The correspondence with the Equines from the French quaternary or pleistocene sedimentary bed (Plate LVII. fig. 6), in the length of the diastema and the position of the canines, is instructively close; the larger size of the wedge-shaped mid incisors, *i* 1 in fig. 7, is due to the limitation of attrition; in the older individual these teeth are worn nearly to their inserted fang (fig. 6, *i* 1).

In the subject of Plate LVII. fig. 8, the permanent canine, *c*, has pushed through the socket; its unworn summit shows the folding back of the margins of the enamel, causing the bicanaliculate inner or hinder surface characteristic of that tooth in Equines. In the lower molar series of the Equine from the freshwater beds of the Puy-de-Dôme, the fold *f* so nearly touches the same part of the fold *g* as to suggest that they may have been continuous at the earlier stage of attrition shown in the young colt from Bruniquel.

I would have given the dentition, and the results of comparison of my fossils therewith, of the Ghor-khur (*Equus onager*, Pallas*), of the *Equus tæniopus*, Heuglin, and of the Koulan (*Equus hemippus*, Isid. Geof. St.-Hilaire†); but to wait for such opportunities threatened indefinite delay. The observations, moreover, described in the preceding pages, carried on at intervals of leisure, and as opportunities occurred, had brought me to conclusions relative to the Equine fossils of the Cavern of Bruniquel which seemed worthy of being communicated to the Royal Society. I nevertheless can only regard them as a commencement of that which the subject of Equine fossils in general requires. There remains to be worked out, and no doubt ultimately will be worked out, the range of variety to which the dental characters of the several existing species of Equines may be subject.

Specimens, however, of Dshiggettais, Kiangs, and other wild Asses or unstriped Equines, are rare in Menageries and Museums, as are also those of Zebras, Quaggas, Dauws, and others of the striped species.

But a beginning must be made; and if I may judge from my own wants and wishes, the figures illustrative of the present Memoir will prove acceptable to those who may be better qualified to carry on this line of palæontological research.

I subjoin a note of the range of size, expressed in French millimetres, which I have observed in certain molars of existing Equines, as to antero-posterior extent or length of grinding-surface, upper jaw:—

In *Equus caballus*, *p* 2, from millims. 36 to 40; *p* 3, from millims. 28 to 32; *p* 4, from millims. 26 to 30; *m* 1, from millims. 24 to 28; *m* 2, from millims. 25 to 27; *m* 3, from millims. 28 to 37 (*m* 3 in some varieties of Horse does not exceed *p* 3 in length); *d* 2, from millims. 34 to 39; *d* 3, from millims. 27 to 30; *d* 4, from millims. 28 to 29.

In *E. asinus*, *p* 2, from millims. 28 to 35; *m* 3, from millims. 21 to 24.

In *E. zebra*, *p* 2, from millims. 32 to 35; *m* 3, from millims. 23 to 24.

In *E. quagga*, *p* 2, from millims. 37 to 39; *m* 3, from millims. 22 to 29

In *E. hemionus*, *p* 2, from millims. 33 to 36; *m* 3, from millims. 22 to 25.

In *E. Burchelli*, *p* 2, millims. 38; *m* 3, millims. 25.

In *E. spelæus*, *p* 2, from millims. 37 to 39; *m* 3, from millims. 25 to 27.

For further aid in comparisons the following dimensions are given in the subjoined Table of Admeasurements.

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* A mare, from Kutch, was received at the Zoological Gardens in May 1849.

† A mare, from Syria, was presented to the Zoological Society in October 1854.

TABLE OF ADMEASUREMENTS.

	Length of series of grinders.				Length of series of premolars, *p* 2, 3, 4.		Length of series of molars, *m* 1, 2, 3.		Length of series of premolars, *p* 2, 3, 4.		Length of series of molars, *m* 1, 2, 3.		From *p* 2 to *i* 3.		From *p* 2 to *i* 3.	
	Upper.		Lower.		Upper.		Upper.		Lower.		Lower.		Upper.		Lower.	
	in.	lines.	in.	lines.	in.	lines.	in.	lines.	in.	lines.	in.	lines.	in.	lines.	in.	lines.
Equus caballus, large var.	7	7	7	8	3	11	3	8	3	9	3	11	5	7	5	0
—— ——, small var. ...	6	8	6	7	3	9	3	1	3	4	3	3				
—— asinus	5	9	6	0	3	2	2	7	3	$1\frac{1}{2}$	2	9	3	0	2	8
—— hemionus	6	0	6	1	3	4	2	8	3	2	2	10	4	0	3	$4\frac{1}{2}$
—— quagga	6	4	6	5	3	4	3	0	3	5	3	0	3	0	2	9
—— Burchelli	6	6	6	7	3	6	3	0	3	6	3	1	3	5	3	4
—— zebra	6	6	......		3	6	3	0	......		......		......		......	
—— spelæus, No 1*......	6	6	......		3	6	3	0	......		......		......		......	
—— ——, No. 2†	7	2	......		4	0	3	2	......		......		......		3	6
—— ——, No. 3‡	6	$7\frac{1}{2}$	......		3	$7\frac{1}{2}$	3	$0\frac{1}{2}$	......		......		......		......	
—— ——, No. 4§	7	0	7	3	4	$7\frac{1}{2}$	3	0	3	9	3	6	......		3	6

From other parts of the enduring framework of the Horse-tribe, more or less petrified in the brecciated deposits of Bruniquel, but little aid can be had in the determination of the question of their affinities in that natural and slightly differentiated group. Every bone containing a marrow-cavity has been split or fractured to get access to that savoury and nutritious substance. The dental canal and roots of the teeth have been exposed in every specimen of upper and lower jaws for the same purpose. Some carpal and tarsal bones are entire: amongst the latter is the characteristic astragalus of an *Equus*, showing its deep and oblique pulley. It differs from that of our present average-sized horses only in the same degree of size as do the teeth and jaws previously described, and it doubtless belongs to the same race.

A portion of femur shows a longitudinal extent from the lower part of the third trochanter to the upper part of the fossa, giving origin to the gastrocnemius externus, which, compared with the circumference of the shaft midway between these parts, indicates a proportion of femur corresponding, in relative length to thickness, more with that of the Horse than with that of the Ass.

Concluding Remarks.—The conclusions to which I have been led by the preceding comparisons are as follows:—First, that the Bruniquel Equine fossils are identical in race with those which have been obtained from certain freshwater postpliocene or quaternary beds in France, as from the locality, for example, traversed by the river Allier, near the Tour de Juvillac, Puy-de-Dôme. They present a closer resemblance, in all the points compared, with those 'fossils of deposit' than with any other known extinct or recent Equine. Secondly, I infer from the sum of the known characters of this rather small and seemingly extinct race of Equines, that they were more nearly allied to the true Horses, forming the limited genus *Equus* of modern Mammalogy, than to the Zebras and

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* Var. A, Plate LX. fig. 2. † Var. B, Plate LX. fig. 3.

‡ From freshwater beds, Tour de Juvillac, Puy-de-Dôme, smaller variety.

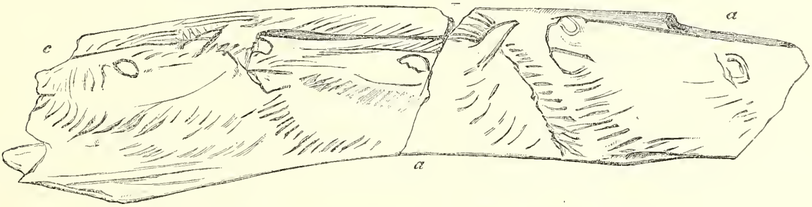
§ From freshwater beds, Tour de Juvillac, Puy-de-Dôme, larger variety.

Asses, included in the genus *Asinus* of Gray. These latter, whether striped or unstriped, want, as is well known, the callosity on the inner side of the leg, called ‘châtaigne’ by French veterinarians and ‘sallander’ by English ones, in the hind limbs, and have it only in the fore limbs; while the true Horses have it in both fore and hind limbs. The species of *Asinus* have the long hair of the tail limited to a terminal tuft, the rest being slender and clothed with short close hair like the skin of the body: in the species of *Equus* proper the skin of the tail developes the long hair from its base, giving the graceful flowing form to that appendage in that higher group. Asses and Zebras have a short close ‘pelage,’ at least in the summer season; and at no part of the year have I ever seen in any of the striped or unstriped *Asini* at our Zoological Gardens such a beard-like development of hair from the skin of the mandible as that which is notable in the wild Horse of the Pampas and in our own unkempt Exmoor or Shetland ponies and cart-horses, but which the neat groom is careful to eradicate in the trim horses used for carriage-draught or for saddle.

The artistic instinct or propensity of the cave-dwellers with flint and bone weapons, of which I communicated examples in my former Paper*, has left interesting and unexpected evidence, helping toward the solution of the main question as to the nature of the wild Equines which they, most probably, hunted, trapped, and killed for food.

On the two sides of a portion of one of the broad and flat ribs of the Horse, the primeval artist has cut the outline of the head of the living animal. Repeating his sketch as often as the scale of his drawing and the size of the smooth bone selected would permit, he has thus been able to put two heads and part of a third on each side of his bone (Cuts, figs. 7 & 8).

Fig. 7.



Outlines of heads of horses cut on a horse's rib, from the Cavern of Bruniquel.

The collocation may show his intention to suggest the herds in which the wild animals congregated, and the single lines or files in which they fled†. The differences of size may also have been meant to indicate the horse (*a*), the mare (*b*), and the foal (*c*). Three of the heads, two on one side and one on the other, are of the largest size, and measure from the setting-on of the ear to the nostril 1 inch 8 lines, or 1 inch 9 lines. A single head on one side (fig. 8, *b*) gives 1 inch 5 lines in the same admeasurement; a single head on the opposite side (fig. 7, *c*) gives but 1 inch; the depth of the head in this indication of a colt or filly is in proportion to the minor length, as compared with the full-sized specimens. But what is most to my present purpose is the evidence of the length of the beard-like hairs in the stallions, and the pointed ears in all. The short pointed ears, associated with the bushy tail, are evidence of the affinity of the animal figured in cuts 7 & 8, to *Equus* proper. The ears alone would not have been of value, since those of the Kiang have the shape and almost the proportion of the horse's ears. In the wild Ass or Onager, the length of the ears and their less acute termination are conspicuous. The ears are large and obtuse in all the Zebrine groups. The profile of the fore part of the head (chaffron or 'chanfrein') of the mature horses is straight, as in the Greek sculptures[*]. It is a little convex in the outline of what I conclude to be the head of a young animal (fig. 7, *c*), in which, from the jaws not bearing the full dentition, they are shorter, and the eye (orbit) is accordingly more nearly midway between the ear and the angle of the mouth.

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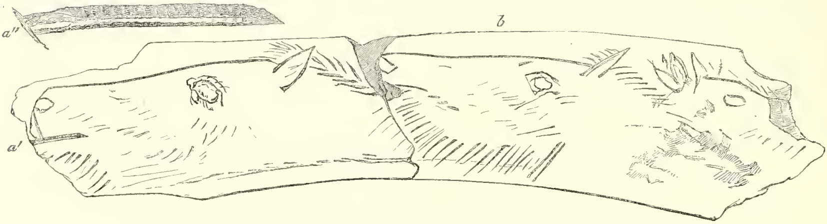
* See Philosophical Transactions, 1869, p. 517, Cuts 5 & 6.

† Colonel Hamilton Smith, who was attached to the allied armies in the Campaign of 1813–14, gives, perhaps, the most trustworthy evidence of a race of wild Horses, taken from an intelligent orderly Cossack, who served as a Russian interpreter, and who had passed ten or twelve years in the Mongolian deserts near the frontier of China. He describes the chin and muzzle of such horse as beset with bristles, the tail bushy from the root, but not descending lower than the hocks; when alarmed they fled “in lines or files” with the stallions in advance and also bringing up the rear. (In ‘Jardine's Naturalist's Library,’ Equidæ, 12mo, 1841, p. 161.)

Fig. 8.



Outlines of heads of horses cut on a horse's rib, from the Cavern of Bruniquel.

The accuracy with which the characters of *Cervus tarandus* are rendered, in the outline of the head and antlers of which a figure was communicated to the Royal Society in Part I. (June 9th, 1864: Cuts, figs. 5 & 6, p. 517), justifies the inferences deduced from the works of an equally accurate primeval artist, to whom we are now indebted for, perhaps, the most satisfactory evidences of the affinities of the *Equus spelæus*. The mouth (Cut, fig. 8, *a'*) is not indicated by a mere line or simple incision; the outer ridges of the Equine molars must have suggested the character of a multiplicity of teeth. Viewed by the hand magnifier, one sees, in fact, that the prehistoric Troglodyte has expressed his idea of the interlabial structures, conventionally no doubt, by a row of minute notches above and below the line representing the meeting of the molars. An accurate drawing of this appearance, so magnified, is given at a'', fig. 8. But the help which these draughtsmen of the old cave-dwelling people have undesignedly contributed to the modern man of science does not end here. The difference between the " cauda undique setosa "* and the " cauda extremitate setosa "† is such as could not have escaped the sharp-eyed hunter, nor have failed to be represented in the outlines by the artist of the tribe. Hitherto, so far as I learn, at Bruniquel, only the heads of the contemporary wild horses have been engraved on bone. But in the Cavern of La Madelaine, Dordogne, the antler of a Reindeer (a shed one) was found covered with more coarsely graven outlines of entire Equines (fig. 9), showing the large or coarse head, characteristic of the wild animal, the short prick-ears, and a tail which unquestionably indicates the wholly clothed character of that part in the true or restricted *Equus* of modern mammalogists. It is repeated in each of seven outlines cut on this antler, is short, or does not extend beyond the hock, and in none is there the slightest indication of a terminal expansion or tuft suspended on a slender stem as in Zebras and Asses.

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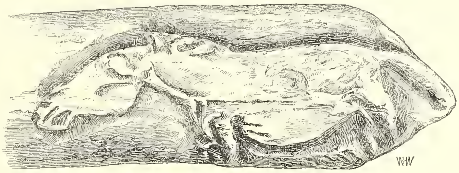
[*] On the Elgin Marbles the domesticated horses are not larger than the wild animals which have left their remains in the Bruniquel cave.

Fig. 9.



Outline of horse, cut on a Reindeer's antler, from a Cave in the Dordogne.

No satisfactory evidence of an aboriginal feral *Equus caballus* has yet been obtained by the Naturalist. No specimen of such exists in any Museum. The doubts expressed by FORSTER and PALLAS as to the alleged wild horses of the Ukraine, viz. that they might be descendants from strayed domestic horses, have not yet been cleared up. I believe the illustrations contained in the present Paper to be the best, if not sole, evidences of the wild originals of some of our domesticated breeds. Like the alleged wild horses of Prussia, those of Aquitaine, in the time of the flint-armed hunters and cave-dwellers, were doubtless " shy and difficult of capture, but very good venison "‡.

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* LINNÆUS, char. of *Equus caballus*, Systema Naturæ, vol. i. p. 100.

† LINNÆUS, char. of *Equus asinus*, Systema Naturæ, vol. i. p. 100.

‡ ERASMUS STELLA, de Origine Borussorum, quoted by Colonel HAMILTON SMITH, *op. cit.* p. 158.

Description of the Plates.

PLATE LVII.

Fig. 1. Working-surface of teeth of upper jaw, *Equus caballus*, ♂.
Fig. 2. Working-surface of teeth of lower jaw, *Equus caballus*, ♂.
Fig. 3. Working-surface of deciduous molars, upper jaw, *Equus caballus*, ♂.
Fig. 4. Working-surface of deciduous molars, lower jaw, *Equus caballus*, ♂.
Fig. 5. Working-surface of lower series of molars, *Equus spelæus* (Bruniquel).
Fig. 6. Working-surface of teeth of lower jaw, *Equus spelæus* (Puy-de-Dôme).
Fig. 7. Fore part of lower part of mandible with first permanent incisors and first right grinder in place, *Equus spelæus* (Bruniquel).
Fig. 8. Portion of left ramus, lower jaw, with first grinder right and point of permanent canine protruding, *Equus spelæus* (Bruniquel).

PLATE LVIII.

Permanent dentition of *Equus asinus* and *Equus hemionus*.

Fig. 1. Working-surface of teeth of upper jaw, *E. asinus*, ♂.
Fig. 2. Working-surface of teeth of lower jaw, *E. asinus*, ♂.
Fig. 3. Working-surface of teeth of upper jaw, *E. hemionus*, ♂.
Fig. 4. Working-surface of teeth of lower jaw, *E. hemionus*, ♂.

PLATE LIX.

Permanent dentition of *Equus quagga* and *Equus Burchelli*.

Fig. 1. Working-surface of teeth of upper jaw, *E. quagga*, ♂.
Fig. 2. Working-surface of teeth of lower jaw, *E. quagga*, ♂.
Fig. 3. Working-surface of teeth of upper jaw, *E. Burchelli*, ♀.
Fig. 4. Working-surface of teeth of lower jaw, *E. Burchelli*, ♀.

PLATE LX.

Fig. 1. Working-surface of upper permanent grinders, *Equus zebra*, ♂.
Fig. 2. Working-surface of upper permanent grinders, *Equus spelæus*, var. A.
Fig. 3. Working-surface of upper permanent grinders, *Equus spelæus*, var. B.
Fig. 4. Working-surface of first and second molars, and of the germs of last premolar and last molar of *Equus spelæus*, var. B.
Fig. 5. Outside view of last two deciduous molars and of germs of three functional premolars of *Equus spelæus*, var. B.

Fig. 6. Working-surface of the deciduous molars and germ of premolar, *p* 2, of *Equus spelæus*, var. B.

All the figures are of the natural size; the letters and numerals are explained in the text.

WOODCUTS.

Fig. 1. Details of grinding-surface of upper molar, *Palæotherium.*
Fig. 2. Details of grinding-surface of upper molar, *Paloplotherium.*
Fig. 3. Details of grinding-surface of upper molar, *Hipparion.*
Fig. 4. Details of grinding-surface of upper molar, *Equus caballus.*
Fig. 5. Details of grinding-surface of lower molar, *Rhinoceros.*
Fig. 6. Details of grinding-surface of lower molar, *Equus caballus.*
Fig. 7. Inner surface of a portion of rib, on which have been cut outlines of the head of male, *a*, and young, *c*, of the living *Equus spelæus.*
Fig. 8. Outer surface of the same portion of rib of *Equus spelæus*, on which have been cut outlines of the head of male, *a*, and female, *b*, of that species when alive. (From the Cave of Bruniquel.)
Fig. 9. Portion of antler of Reindeer (*Tarandus*), on which has been cut an outline of the living *Equus spelæus.* (From the Cave of La Madelaine, Dordogne.)

BRITISH MUSEUM
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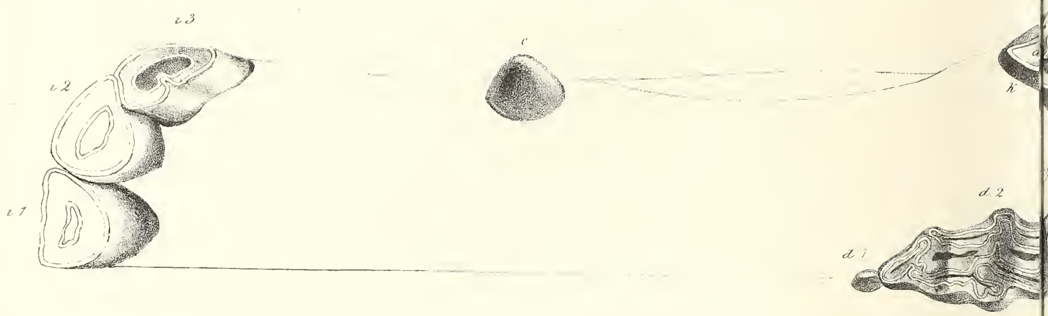
1



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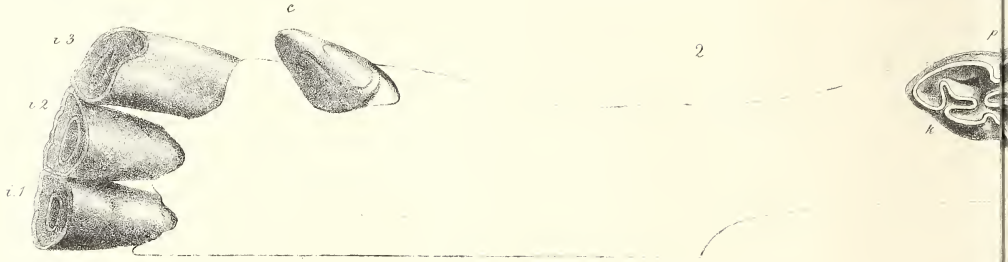

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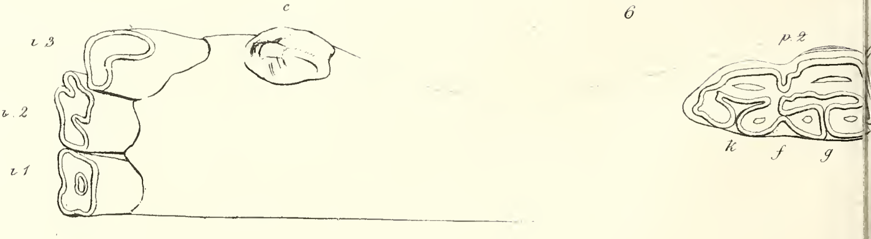

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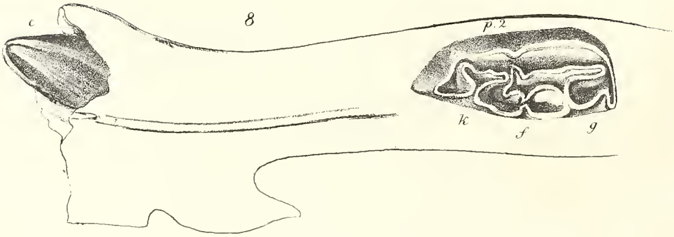
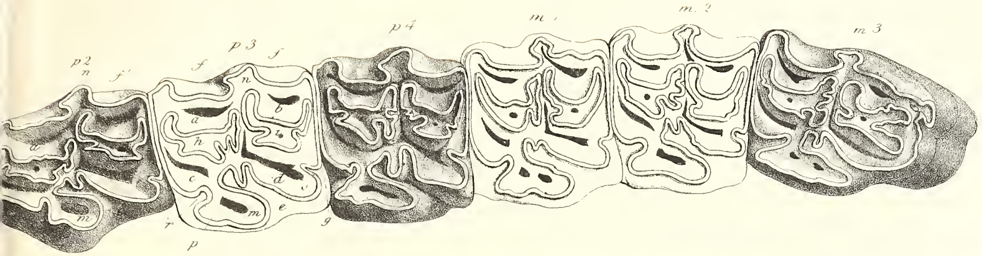
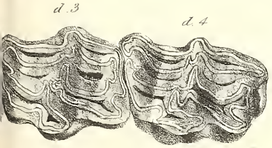


From nat. on stone by J. Erxleben.

1-4. EQUUS CABALLUS ♂
6.7. EQUUS SPELÆUS





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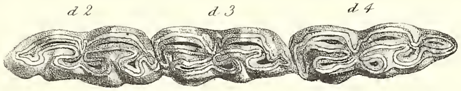

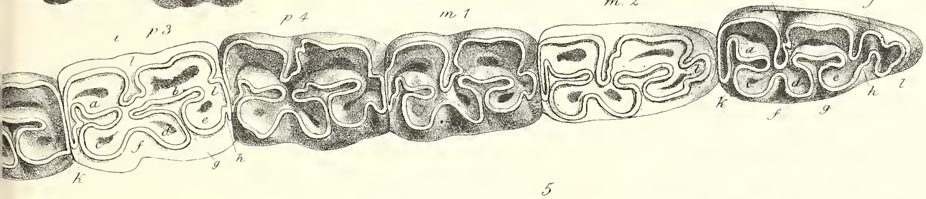

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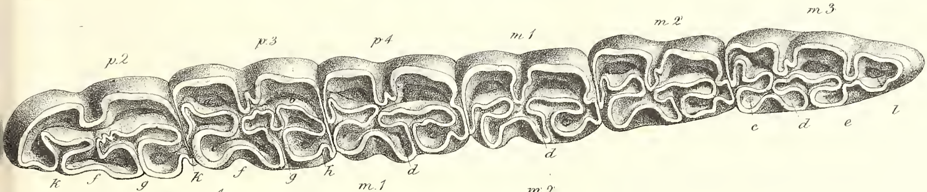

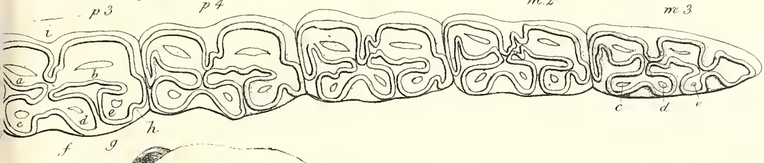

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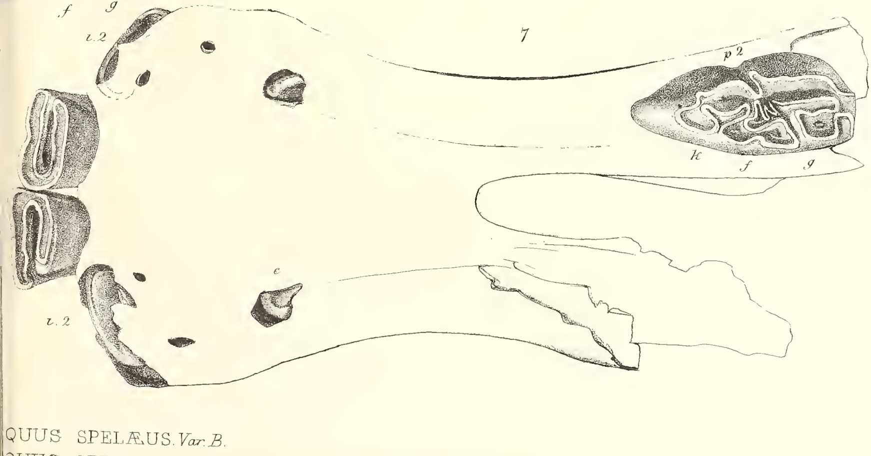
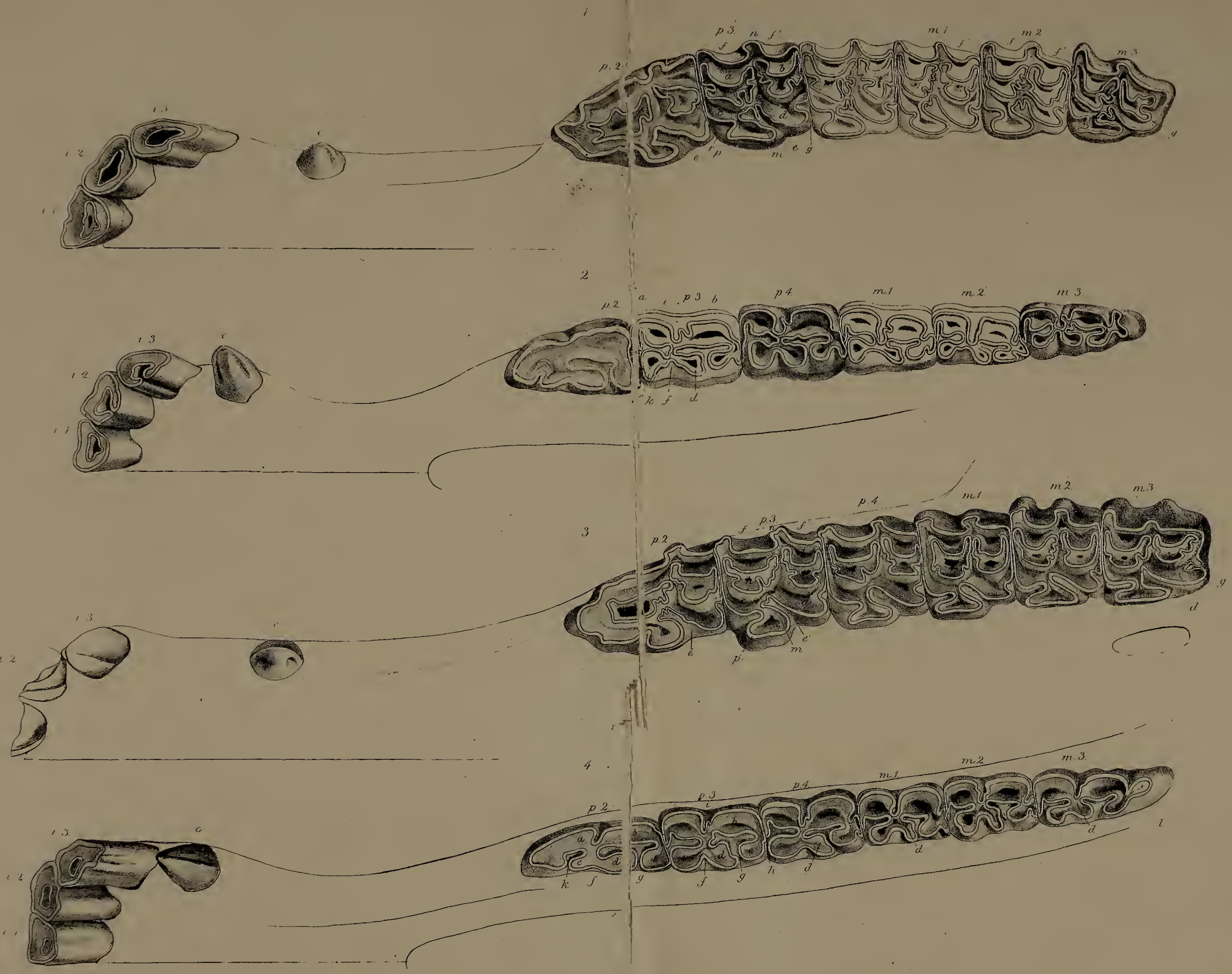


QUUS SPELÆUS. Var. B.

QUUS SPELÆUS. Ow. 6.

W West imp.

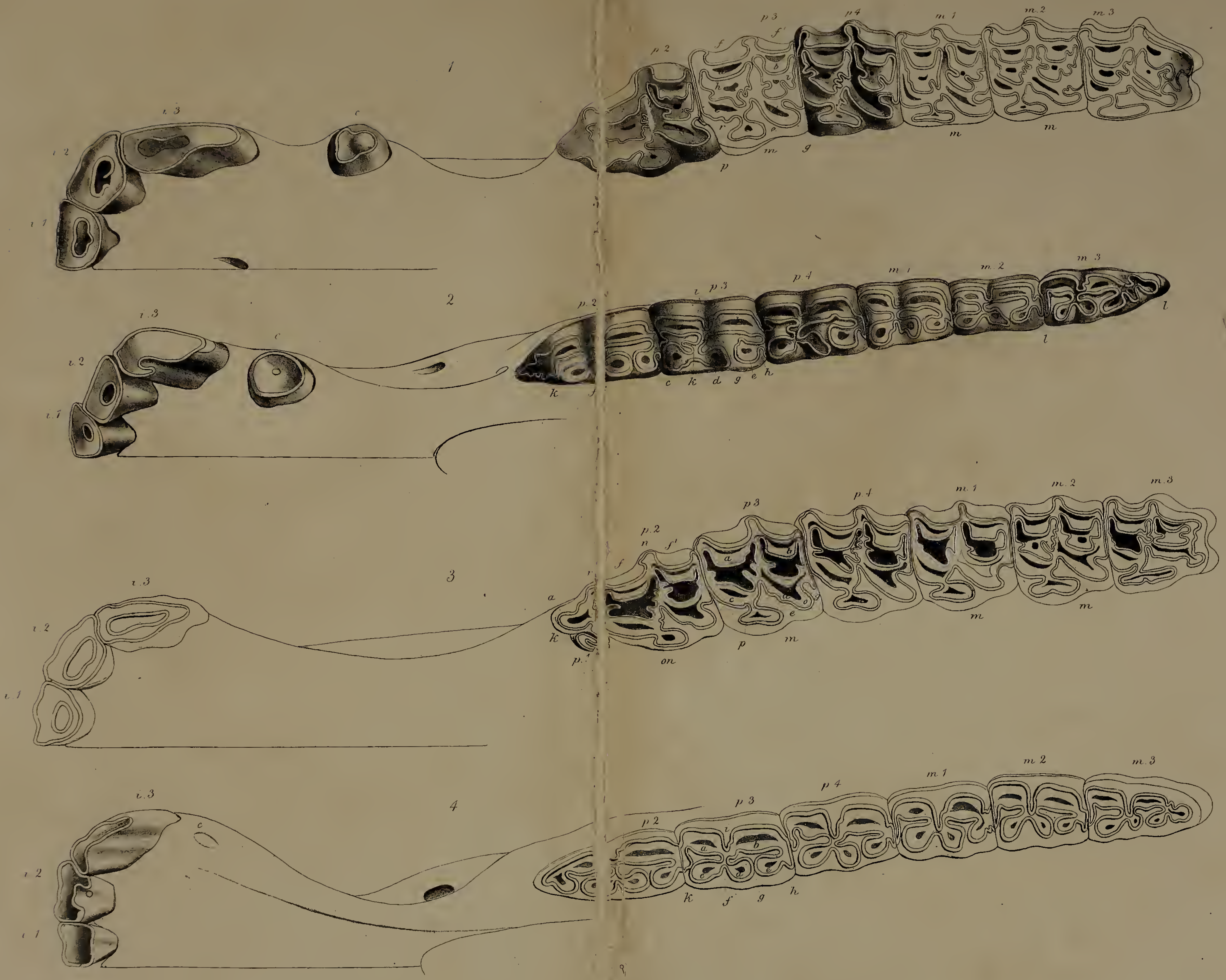
BRITISH MUSEUM NATURAL HISTORY.



J. Erxleben

W. West imp.

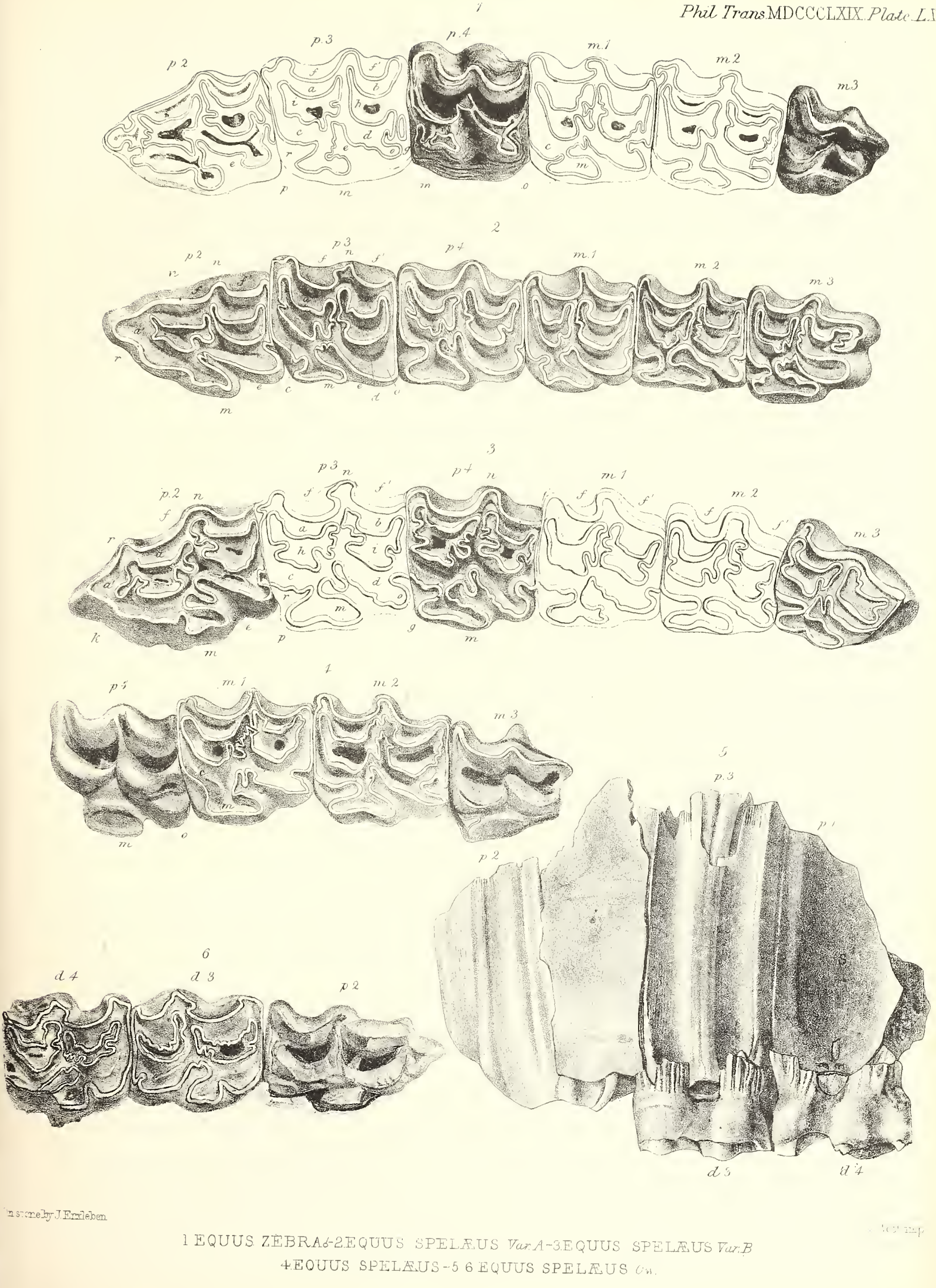
1. 2. EQUUS ASINUS. 3. 4. EQUUS HEMIONUS



On stone by J. Erxleben

W. West imp.

1. 2. EQUUS QUAGGA — 3. 4. EQUUS BURCHELLI ♀.



On stone by J. Erxleben

1 EQUUS ZEBRA ♂ - 2 EQUUS SPELÆUS *Var. A* - 3 EQUUS SPELÆUS *Var. B*
4 EQUUS SPELÆUS - 5 6 EQUUS SPELÆUS *Ow.*

BRITISH MUSEUM NATURAL HISTORY.

XVII. *On Fossil Remains of Equines from Central and South America referable to* Equus conversidens, Ow., Equus tau, Ow., *and* Equus arcidens, Ow. *By Professor* Owen, *F.R.S. &c.*

Received November 17, 1868,—Read February 4, 1869.

Having examined the dental characters of existing species of the Horse-kind so far as seemed requisite for the determination of the Equine remains found in the Cavern of Bruniquel*, I have been enabled, on the same basis of comparison, to deal with other Equine fossils, and propose to communicate in the present Paper the results of this labour in elucidation of those which have reached me from some American localities.

In the account of the Mammalian Remains brought from South America in the 'Voyage of the Beagle,' I described and figured an upper molar tooth as belonging to a species of *Equus*†; and this tooth, having been found by Mr. Darwin imbedded in the quartz shingle of cemented pebbles at Punta Alta in Bahia Blanca, together with remains of *Megatherium*, *Megalonyx*, *Mylodon*, and *Scelidotherium*, I concluded not to be a tooth of a horse imported by Europeans into South America, but to have belonged to an Equine species which had coexisted with those large Megatherioids and had, with them, become extinct a[illegible] prehistoric period. An Equine upper molar tooth of similar pattern, included in the collection of fossils from the same 'Voyage,' was labelled as having been found in red argillaceous (postpliocene ?) deposits at Santa Fé, in the province of Entre Rios, Buenos Ayres; and this tooth being associated in the series with parts of *Mastodon* and *Toxodon* confirmed me in the above conclusion‡.

In the Monograph of 1840, above quoted, I did not feel, however, that I had sufficient grounds for differentiating the species to which the two detached fossil teeth had belonged from *Equus caballus*, the upper molars of which seemed to differ from the fossils chiefly in a slight superiority of size, with some seemingly unimportant modifications of the complex but characteristically Equine enamel-folds.

But improved practice and attention to detail in the course of my work on 'Odontography' led me to appreciate the value of the latter indications, and to note a greater degree of curvature of the entire tooth, and also a greater relative antero-posterior diameter of the crown as compared with *Equus caballus*. I accordingly pointed out the distinctive character of these teeth as those of *Equus curvidens* in that work§; and I entered the specimens, Nos. 1030 & 1031, as of an *Equus curvidens* in my 'Catalogue of Fossil Organic Remains in the Museum of the Royal College of Surgeons,' vol. i. "Mammalia and Birds," 4to, 1845, p. 235.

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* *Ante*, pp. 535–557.

† The Zoology of the Voyage of H.M.S. 'Beagle,' pt. i. Fossil Mammalia, 4to, 1840, p. 108, pl. xxxii. fig. 13.

‡ *Tom. cit.* p. 109.

§ Odontography, p. 575 (1842).

It is unlikely—seeing the avidity with which the Indians of the Pampas have seized and subjugated the stray descendants of the European horses introduced by the Discoverers and 'Conquistadors' of South America, and the able use those nomad natives make of the multitudinous progeny of the Spanish war-horses at the present day—that any such tameable Equine should have been killed off or extirpated by the ancestors of the South-American aborigines. The circumstances of the discovery and the fact of the extinction in South America of a species of Horse would point to some other cause than that of the hostility of man to so useful an animal; and we might then in like manner give the benefit of such doubt as to extinction by human means to the contemporaries of the *Equus curvidens*, viz. *Megatherium*, *Toxodon*, *Macrauchenia*, *Glyptodon*, &c.

I am now able to adduce other evidences confirmatory of the distinctive characters of *Equus curvidens* from all known Equines, recent and fossil, of the Old World of geographers, and at the same time to extend the geographical distribution, in the New World, of this or a nearly allied species to Brazil and to Central America, in a direction toward the locality where LEIDY has indicated its remains[*].

With regard to fossil evidences of the Horse-kind in Brazil, we are mainly indebted to the persevering researches of that excellent naturalist, Dr. P. W. LUND, who devoted the last few years of his life, spent on account of failing health in Brazil, to a most valuable and instructive investigation of the limestone caverns in the interior Highlands of that country. In a letter dated "Lagoa Santa, 4th October, 1841," Dr. LUND communicated to the Royal Academy of Sciences, Copenhagen, a continuation of his Account of the Limestone Caves in the Interior of the Highlands of Brazil, in which, among the contents of the Cave B, Lapa do Bahu, appears "No. 16, *Equus neogæus*," (IV.) vol. xi. (1845) p. 76[†]. No other notice of the Equine fossils or of the character of the extinct species appears in this communication. In a subsequent letter, dated "Lagoa Santa, 22nd November, 1844," Dr. LUND gave results of later researches in those caves, which were published with plates in (IV.) 1846, vol. xii. p. 59. In this letter the genus *Scelidotherium* is cited, and in the 'Summary of the fossils from cursory inspection' (p. 86) there appears "No. 17, *Equus* aff. *caballo*."

Of this he proceeds to say that "the greater part of the skeleton of a young individual was obtained from one of the caves, which proved to be identical with that previously found, in the Sumidouro cave, associated with human bones" (p. 89). And we are enabled to judge of an instructive character of this Equine by the figure of the grinding-surface of the fourth molar, right side, upper jaw ("Fjerde Kindtand i hoïre Oberkjæve," p. 93, (IV.) tab. xlix. fig. 2).

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[*] Dr. LEIDY notices some fossil Equine teeth as showing characters of *Equus curvidens* which had been discovered in upper tertiary deposits in Kentucky, North America: see 'Proceedings of the Academy of Sciences of Philadelphia,' September 1847, p. 262. Dr. BURMEISTER refers to the same species some teeth from the "laguna Siasgo of the Rio Salado, Buenos Ayres," in the 'Anales del Museo Publico de Buenos Ayres,' 4to, 1867, p. 245, pl. xiii.

[†] The Roman numeral (IV.) indicates, in this Paper, the work entitled "Det Kongelige Danske Videnskabernes Selskabs Natur. og Mathematiske Afhandlinger." The previous communications by Dr. LUND on this subject to the Danish Academy were translated by the Rev. W. BILTON, M.A., and published under the title "View of the Fauna of Brazil, previous to the last Geological Revolution," in the 'Magazine of Natural History,' New Series, 1840, p. 1. Up to that date he appears not to have met with Equine remains in the Brazilian caves.

This figure, to which I have added the symbols of characteristic parts of the grinding-surface used in my preceding memoir, is reproduced in fig. 12, Plate LXII., for the purpose of comparison with the type specimen of *Equus curvidens*, fig. 2, Plate LXI.

Of the difference of LUND'S *Equus* aff. *caballo* from his *Equus neogæus* and *Equus principalis*, the figures of the grinding-surface of the molars given in his tab. xlix. figs. 1 & 3 (figs. 9 & 10, Plate LXII.) leave no doubt. These specimens, Dr. LUND says, were extracted "from very old breccia"[*]. Without entering into any descriptive detail or comparison of them (which, indeed, would have been barely if at all available in the absence of the requisite descriptions and figures of the teeth of known species of *Equus*), he remarks, that[†] "*Equus neogæus* is more remote in the formation of the teeth from the common form of Horse than KAUP'S *Hippotherium*; and since that animal already shows such essential deviations from the single-hoofed form in the structure of the feet, it is to be presumed that *Equus neogæus*, when it is better known, will present still more considerable deviations. This is even more the case with *Equus principalis*, which, to judge from its deviating form of tooth, may well have possessed extremities as different from those of the Horse, as those animals which we, with OWEN, have learned to recognize as *Macrauchenia*, or, in other words, may be the same animal."

Leaving, for a while, this question, I will merely now remark that, through Dr. LUND'S discoveries of at least one kind of horse remarkably distinct from any existing species, and, I may add, any known European fossil Equine, all reasonable doubt as to that form or family of perissodactyle Ungulate having coexisted with *Megatherium* &c. in pliocene or postpliocene time, in South America, was set at rest.

Passing to the *Equus* aff. *caballo*, LUND, its discoverer, in reference to the association of its remains with those of Man, speculates as to "whether it may have been used by the inhabitants in those remote times as a domestic animal. It may," he proceeds, "easily be supposed possible to solve this question by a simple examination of the remains of the animal; but it will in all cases require a comprehensive comparison of a large number of specimens, since one of the results of domestication is to enlarge the limits for the play of individual variation. Upon the small number of specimens I have had occasion to examine, which do not amount to more than three, naturally no conclusion in this respect can be founded; yet I must not omit to remark that in one of these specimens is observed a pathological phenomenon, namely, a deformity in the structure of one of the molar teeth. All three specimens, notwithstanding they were partly young animals, considerably exceeded in size full-grown specimens of the race of horses introduced by the Portuguese."—*Op. cit.* pp. 89–91.

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[*] "Der ikkun forekomme i meget gamle Breccier," (IV.) tom. xii. p. 89.

[†] "Thi *Equus neogæus* fjerner sig i Dannelsen af Tænderne meget mere fra den almindelige Hesteform, end KAUP'S *Hippotherium*, og da dette Dyr allerede udviser saa væsentlige Afvigelser fra Eenhoverformen i Bygningen af Födderne, er det at formode, at *Equus neogæus*, naar den bliver bedre bekjendt, vil frembyde endnu betydeligere Afvigelser. Dette gjelder endnu mere om *Equus principalis*, der efter sin afvigende Tandform at slutte, meget vel kunde have besiddet Extremiteter saa forskjellige fra Hestens, som de, vi ved OWEN have lært at kjende for *Macrauchenia*, med andre Ord, være det samme Dyr."—*Op. cit.* p. 90.

With respect to the malformation ('deformitet'), of the nature of which no account is given, I may refer to the case of a hollow tumour near the base of the crown, described and figured in my 'British Fossil Mammals,' pp. 388, 389, figs. 146, 147, as occurring in a permanent lower molar of an '*Equus fossilis*' from the blue clay at Cromer, an instance which, from the nature of the fossil and its association with the Proboscidia and other extinct mammals of that formation, exemplifies the liability to disease in the mammals of that (newer pliocene) period.

Returning to Dr. LUND's illustrations of the Equine fossils from the Brazilian caves, I may first remark that the one (fig. 12, Plate LXII.) discovered in the Sumidouro cave, in which human remains were found, in the points in which it differs from the existing Horse (Plate LVII. fig. 1, *p* 4) in regard to the pattern of the grinding-surface, and in size and shape, corresponds with that tooth on which the species *Equus curvidens* had been previously founded. No evidence whatever of the contemporaneity of the equine with the human remains in the Brazilian cave is adduced. A comparison of fig. 2, Plate LXI. (*Equus curvidens*, Ow.) with fig. 12, Plate LXII. (*Equus* aff. *caballo*, Ld.[*]), fig. 9, Plate LXII. (*Equus neogæus*[†]), and fig. 10, ib. (*Equus principalis*, Ld.)[‡] will suffice to show that only to the first of LUND's species can the *Equus curvidens* be referred, if, indeed, specific identity can be safely predicated on so few grounds as are afforded by the remarks of the Danish explorer. Unfortunately, in no part of Dr. LUND's descriptions is any mention made of the degree of curvature of the teeth. It is possible that they were not obtained from the breccia sufficiently entire to yield this character; otherwise it could hardly have escaped the notice of so acute an observer[§].

I shall recur in the sequel to the characters of the teeth which are unequivocally distinct from those of *Equus curvidens*, Ow., and of *Equus* aff. *caballo*, Ld., and now proceed to the evidence of extinct Equines, more nearly allied to these latter, from a locality in Central America.

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[*] (IV.) Tab. xlix. fig. 2.

[†] Ib. fig. 3.

[‡] Ib. fig. 1.

[§] I have also to regret the want of notice of this character in the account of the teeth of Equines, alleged to be fossils, brought from South America (locality not stated) by Count DE CASTELNAU, and from Tariga in Bolivia by Mr. WEDDELL. Professor GERVAIS, who has described and figured these specimens, remarks, "Il nous parait probable que cet *Equus macrognathus* [Mr. WEDDELL's specimen], notre *Equus americanus* du Chili, *l'Equus curvidens* de Buenos Ayres, et *l'Equus neogæus* des cavernes du Brésil, sont des animaux d'une seule et même espèce" —p. 34, pl. vii. 'Expédition dans les parties centrales de l'Amérique du Sud, &c. (1843–1847) sous la direction du Comte FRANÇOIS de CASTELNAU,' Septième Partie, Zoologie (Anatomie par M. PAUL GERVAIS), 4to, 1855. This remark leads me to doubt whether the figures in the original Danish Memoir of LUND had been seen by Professor GERVAIS.

I was favoured, through the intervention of R. T. C. Middleton, Esq., of the British Legation, Mexico, in the year 1866, by receiving from Don Antonio del Castillo, Engineer of Mines, resident in Mexico, a series of specimens, casts, and photographs of objects of Natural History, including some fossil remains discovered by the liberal donor in newer Tertiary or Quaternary deposits in the valley of Mexico.

In this series were evidence of at least two species of *Equus*, consisting of portions of jaws with teeth, and detached teeth, found fossil associated with remains of *Mastodon* and *Elephas* and of an extinct *Cervus*.

One of the Equine species (*Equus conversidens*, Ow., Plate LXI. fig. 1) so far corresponds in the size, curvature, and pattern of the grinding-surface of the upper molar teeth with *Equus curvidens*, Ow. (ib. fig. 2) as would have led me to refer it thereto. But the chief Mexican fossil yields a character incompatible with an indication of the arrangement of the teeth in *Equus curvidens*, and which I have not before met with in any kind of horse, viz. a curved convergence of the two series of upper grinders towards the fore part of the palate to a degree exceeding that in other Equines (compare fig. 1 with fig. 6, Plate LXI.); and this peculiarity, with the curvature of the molars themselves, suggests a most interesting and significant resemblance to characters of the upper molars in *Toxodon* and *Nesodon**.

I therefore regard this Mexican fossil as representing a species which I propose to call *Equus conversidens*†.

The specimen (Plate LXI. fig. 1) is a portion of the upper jaw with the right and left series of grinders, and a considerable part of the intervening bony palate. Each dental series includes, as in the rest of the Equine family, three molars and three premolars. The premolars exceed the true molars in size to a greater degree than in *Equus asinus* (Plate LVIII. fig. 1): the true molars, *m* 1, 2, 3, in *Equus conversidens*, e. g., equal *p* 4, *p* 3, and the posterior lobe of *p* 2, while in *E. asinus* they equal *p* 4, *p* 3, and two-thirds of *p* 2, in longitudinal extent of grinding-surface. The disproportion between this extent of the true molars and that of the premolars is still greater in *E. conversidens* as compared with *E. caballus* (Plate LVII. fig. 1).

The last molar, *m* 3, fig. 1, Plate LXI., is relatively smaller than in any old-world Equine. The first premolar, *p* 2, resembles in the minor production of the anterior lobe that tooth in *Equus asinus*, *Equus quagga*, and differs in this respect from *E. caballus*. The grinding-surface, however, retains, as in *Equus* aff. *caballo*, Ld., and in *E. curvidens*, the general conformity of character of enamel-folding so remarkable in all the modern and in the European postpliocene Equine species hitherto described.

As compared with *Equus caballus* (Plate LVII. fig. 1), the dividing ridge (Plate LXI.

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* Compare Plate LXI. fig. 1 with pl. xv. fig. 3, Philosophical Transactions, 1853, and with pl. 1, 'Fossil Mammalia of the Beagle,' 4to, 1840.

† From *converto*, to turn towards; or *conversus*, turned towards, and *dens*, a tooth.

fig. 1, *p* 4, *n*) between the outer longitudinal channels (*f*, *f'*) is narrower, and is not itself grooved along its summit; the dentinal lobes, *c*, *d*, have less thickness or extent in the direction from the outer to the inner side of the tooth; the production, *o*, of the lobe *d* is narrower, and the corresponding production or appendage, *m*, of the lobe *c* is narrower or more compressed from the outer to the inner side of the grinder; it is consequently less prominent; but it is equally expanded both anteriorly and posteriorly to the connecting isthmus. The folding of the enamel of the islands *h* and *i* is about as much as in *Equus curvidens*, Plate LXI. fig. 2, and in *E. caballus*, Plate LVII. fig. 1. But the most distinctive character of the upper grinders of *Equus conversidens* is their disposition in the jaw, denoted by the *nomen triviale* of the extinct Mexican Horse; and to the character of the curvature of the molar series of alveoli may be inferentially added a concomitant modification of the shape of the upper jaw itself, involving that of the lower one.

The bony palate is less arched or concave from side to side in *Equus conversidens* than in any modern Equine.

Admeasurements of part of the upper jaw and teeth of *Equus conversidens*, Plate LXI.

	inches.	lines.
The length of the molar series in a straight line	5	8
„ premolars „	3	3
„ molars „	2	5
Interspace between right and left last molars (*m* 3)	4	0
„ „ first premolars (*p* 2)	2	4

Figure 3, Plate LXI. gives the grinding-surface of the third and fourth milk-teeth, right side, upper jaw, corresponding in size with the third and fourth premolars of *Equus conversidens*, and most probably from a young animal of that species.

From the teeth figured by RÜTIMEYER* as the deciduous molars of the *Equus fossilis* those of *Equus conversidens* differ in the greater degree of compression of the crown from without inwards, in the minor indication of the indent *j*, and simpler character of the fold *g* (marking off the postinternal lobule), in the less prominence and in the flattening of the ridge *n* (dividing the channels *f*, *f'*), and in the minor thickness and prominence of the lobule *m*.

From the milk-molars of *Equus caballus* (Plate LVII. fig. 3, *d* 3, *d* 4) they differ also in the greater fore-and-aft extent and flattening of the external longitudinal ridge, *n*, in the minor relative breadth from without inwards, in the greater proportion of the part of the crown behind the lobule *m*, and in the more generally plicated disposition of the enamel.

The proportions of the crown of the permanent upper molars of *Equus fossilis* (from Kent's Hole, 'British Fossil Mammals,' p. 383, fig. 143) are well brought out in comparison with the immature teeth of *Equus fossilis* figured by RÜTIMEYER (*loc. cit.*); it is probable that those of the deciduous molars of the *Equus fossilis* from Kent's-Hole cavern may have resembled in their proportions those of the extinct Mexican Colt or Filly, represented in Plate LXI. fig. 3. I append, in millimetres and their English equivalents, the

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* Beiträge zur Kentniss der Fossilen Pferde, 8vo, 1863, Taf. I. fig. 12.

Dimensions of the grinding-surface of the upper molars of *Equus conversidens.*

		metre.		inch.	lines.
p 2.	Antero-posterior breadth* . . .	0·030	=	1	$2\frac{1}{2}$
	Transverse breadth*	0·025	=	1	0
p 3.	Antero-posterior breadth . . .	0·025	=	1	0
	Transverse breadth	0·025	=	1	0
m 1.	Antero-posterior breadth	0·022	=	0	$10\frac{1}{2}$
	Transverse breadth	0·021	=	0	10
m 3.	Antero-posterior breadth	0·019	=	0	9
	Transverse breadth	0·018	=	0	$8\frac{1}{2}$

Equus tau, Ow.—This species is indicated by a series of five grinders of the upper jaw, Plate LXI. fig. 4, and of three grinders of the lower jaw, ib. fig. 5. The upper grinders include the three true molars (*m* 1–3) and the two contiguous premolars (*p* 3, *p* 4). They are as much smaller than the corresponding teeth of *Equus conversidens* as are those of the *Asinus fossilis* from the Oreston Cavern (Hist. of British Fossil Mammals, p. 396, figs. 157, 158) compared with the teeth of *Equus plicidens* (*op. cit.* p. 392, figs. 152, 153) from the same cavern, and they indicate a species about the size of the common Ass.

As compared with any of the smaller existing kinds of Equines (Plates LVIII., LIX.), the antero-posterior diameter of the grinding-surface of the crown, especially in the premolars, is in excess; and in this character *Equus tau* also differs from *Equus conversidens*, as it does in the greater relative size, especially antero-posterior breadth, of the last molar, fig. 4, *m* 3: *E. tau* further differs in the greater flattening, from without inward, of the inner lobe, *m*, of most of the molars.

The lower molars of *Equus tau* (Plate LXI. fig. 5, *p* 2, 3, 4) conform to their homotypes above, in their character of narrowness from without inward; the postero-internal enamel-fold, *g*, describes more neatly or definitely than that in other Equines the figure of a short-stemmed capital letter T, which suggested the *nomen triviale* of the second extinct Mexican species.

The fossils representing both species were discovered by Don ANTONIO DEL CASTILLO in the posttertiary deposits, above mentioned, of the Valley of Mexico.

Equus arcidens, Ow.—I have already alluded to the interest with which one views the direction of the deviations of the extinct American Equines from the ordinary type in connexion with the curvature of the grinders, the length of the crown, and the anteriorly converging curve of their sockets, as exemplified in *Equus curvidens* and *E. con-*

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* Across middle of crown.

versidens. I now proceed to the description of some fossil Equine upper molars which show a curvature exceeding as much that in *Equus curvidens* (Plate LXII. fig. 16) as do the teeth in that species as compared with the upper molars of the Horse or Ass. The teeth of *Equus arcidens* (Plate LXII. figs. 3 & 7) compete in this respect with those of the extinct South-American pachyderm for which the term *Toxodon* was devised to express that character; and it may be remarked that both *Toxodon* and *Nesodon* resemble *Equus* in the great length of the crown of the grinding-teeth before the development of any roots, if such occur at any age in *Toxodon.*

The following are the circumstances under which I became cognizant of the present remarkable extinct species of South-American Horse.

I received from Her Britannic Majesty's Minister at Monte Video a letter of the date of May 29th, 1867, referring to the discovery of some fossil mammalian remains and their transmission to the British Museum, in which the Hon. Mr. Lettsom writes, "Since that case was packed I have received four more teeth from the spot where the remains in Boxes 2 and 3 were met with, viz. the 'Arroyo Gutierrez.'"

This 'Arroyo' is a brook falling into the 'Arroyo Negro;' and the spot where the teeth and other fossils were found is ten leagues south of Paysandi, in the Republic of Monte Video.

The other fossils referred to are parts of a Megathere and Glyptodon. The 'four teeth' subsequently received by Mr. Lettsom and transmitted to the British Museum (Plate LXII. figs. 1–8) present a character of the grinding-surface having a general conformity to that in the *Equus neogæus* (fig. 9) and *Equus principalis* (fig. 10) of Lund. Assuming those Brazilian cave-fossil teeth also to have participated with the present ones from the Megatherian deposits of Monte Video in the degree of curvature, they may well indicate a section of extinct Equines having affinities, in the direction hinted at by the acute Danish naturalist, to certain more singular extinct American forms of Ungulates. Both the present and the Brazilian species above cited differ in a marked and unmistakable degree, in the pattern of the grinding-surface of the upper molars (as doubtless also of the lower ones), from *Equus curvidens*, *Equus conversidens*, *Equus tau*, as well as from *Equus macrognathus* (Weddell) (Plate LXII. fig. 11) and *Equus Devillei** (Gervais), represented by figures (unfortunately of half the natural size) in pl. vii. of Castelnau's 'Expédition dans les Parties centrales de l'Amérique du Sud,' &c., 4to, 1855. The four molars from the Arroyo Gutierrez (Plate LXII. figs. 1–8) show the same mineral characters and coloration as do the bones and teeth of the Glyptodon and Megatherioids from that locality, and beget a conviction of their being fossils of the same age.

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* Of *Equus Devillei*, Gerv. (*op. cit.* pl. vii. fig. 11), Professor Gervais appears not to have received any upper molars: he records that, whereas the lower molar series of *E. macrognathus* (*ib.* fig. 4) has a longitudinal extent of 0·195$^{\text{m}}$ (=7″ 7‴), that of *E. Devillei* only gives 0·160$^{\text{m}}$ (=6″ 4‴)—and that they have a rather different disposition of the internal enamel-fold (of the lower molars), which seems from the figure (copied in fig. 17, Plate LXII.) to be less deep and less expanded in the antero-posterior direction than in *E. macrognathus.* In this respect both species, and *à fortiori Equus Devillei*, differ from *E. tau.* With respect to the "*Eq. curvidens* de Buenos Ayres," cited by M. Gervais (*op. cit.* p. 34), I may remark that, as yet, I have not received any evidence of that extinct species of Horse from the Province of Buenos Ayres. The specimens on which the species was founded were obtained at Bajada de Santa Fé, in the Province of Entre Rios, and at Bahia Blanca, on the confines of Northern Patagonia. The species from Buenos Ayres so called by Burmeister (*op. cit.* 1867) has upper molars more resembling those of *Equus principalis,* Ld., and of *E. arcidens,* Ow.

The molars are from the right side of the upper jaw, and probably belonged to the same head. Two show attrition of the grinding-surface; and two, with the body of the tooth fully formed, had not cut the gum.

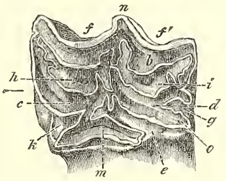
The larger of these unused grinders is probably *p* 4 (I made a section of this tooth, which is figured in Plate LXII. fig. 4); the smaller is *m* 3 (ib. fig. 8). The larger of the worn teeth may be *p* 3 (ib. figs. 1, 2, 3), the smaller one is *m* 2 (ib. figs. 5, 6, 7).

There is strong analogical probability that, in the present as in other species of Equines, the premolars exceeded the true molars in size (as, according to the above determinations, they do) in the degree shown in figures 1, 4, 5, 8.

The proportional smallness of the *m* 3 (ib. fig. 8) resembles that in the similarly unworn tooth of the Zebra (*ante*, Plate LX. fig. 1, *m* 3) and *Equus spelæus*, Ow. (ib. Plate LX. fig. 4, *m* 3). In all these the disparity is less marked when the tooth *m* 3 comes to be worn down to its thicker part; it would then, in *Equus arcidens*, exceed, in regard to relative size to the other teeth, the last molar in *Equus conversidens* (Plate LXI. fig. 1, *m* 3).

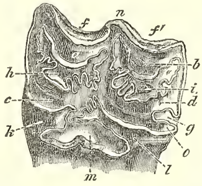
Comparing the tooth which I regard as *p* 4 (Plate LXII. fig. 4) with that in the *Equus fossilis* from the Oreston Cavern (Cut, fig. 1), and comparing *p* 3 of *E. arcidens* with *p* 3 of *Equus plicidens* (Cut, fig. 2), or comparing both teeth of *E. arcidens* with their homologues in the Horse (*E. caballus*, Plate LVII., fig. 1, *p* 3, *p* 4), the antero-external groove *f* is deeper and more semicylindrical in *E. arcidens*; the dividing ridge, ib. *n*, is narrower, more produced, not pinched in at the base as sometimes in *E. caballus*, nor grooved along the summit (Plate LXII. fig. 1, *p* 3, *n*). The dentinal lobes in *E. arcidens* (Plate LXII. fig. 1, *a*, *b*) are narrower transversely, or from the outer to the inner side of the tooth, than in the Horse, and, from the more equal and regular curve of the inner enamel-wall of the lobes, which is nearly parallel with the outer one, these lobes are more definitely crescentic: the Ass's (Plate LVIII. fig. 1) and Zebra's molars (Plate LX.

Fig. 1.



Upper molar, *p* 4, *Equus fossilis*.

Fig. 2.

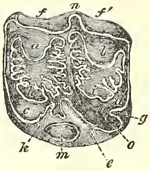


Upper molar, *p* 3, *Equus plicidens*.

fig. 1) rather more resemble, than do the Horse's (Plate LVII. fig. 1), the present fossils in this character. The islands of dentine and cement (Plate LXII. figs. 1, 4, *h*, *i*) in the worn teeth are relatively larger to the rest of the grinding-surface in *Equus arcidens.* They are bounded toward the inner side of the tooth by a ridge of enamel more equably curved and more parallel with the outer ridge than in the common Horse or other old-world species of *Equus*: this ridge, however, is occasionally subject to secondary plications, as shown in the section of the premolar, fig. 4, Plate LXII.

The lobes *c*, *d*, in *E. arcidens* (Plate LXII. figs. 4, 5) are relatively narrower and more regularly crescentic. The lobe *c* sends off the peninsula of enamel *m*, which with the enclosed dentine is, in proportion to the crown of the tooth, much smaller and more simple than in all other known Equines, recent or extinct, excepting the Brazilian *E. neogæus* and *E. principalis*, Ld. (figs. 9 & 10); it is not, however, an insular summit of a distinct column of enamelled dentine as in the Miocene Hipparions (*Hippotherium*, Kaup) (Cut, fig. 3, *m*).

Fig. 3.



Upper molar, *Hipparion.*

In both the worn molars of *Equus arcidens* the peninsular lobule *m* first extends inward and then curves backward, the enamel-wall very slightly expanding in the backward curve. The end of the entering peninsula of cement, *e*, is more expanded as the projecting peninsula, *m*, is more contracted: in *m* 2, fig. 5, it is not encroached upon by any enamel-fold from the lobe *c*; but it is so in the teeth *p* 3 and 4. The fore part of the peninsula *m* extends forward more or less in all other newer tertiary Equines, save *E. neogæus* and *E. principalis*, as it does in all existing species (as at *p*, Plates LVII.–LX.); but less so in the Ass- and Zebra-groups, in which the process *m* is relatively smaller than in the Horse. Thus the more simple shape as well as smaller size of the process *m* in Plate LXII. figs. 1, 4, 5, 9, 10, is amongst the well-marked characteristics of the upper molars of the group represented by *Equus arcidens*, *E. neogæus*, and *E. principalis.*

The entering fold, *g*, figs. 1, 4, 5, Plate LXII., which marks off an appendage of the lobe *d*, is relatively deeper in *Equus arcidens* than in *E. caballus*; and the process, *o*, of *d* is more distinct and more like a posterior serial repetition of the process *m* in *E. arcidens.*

The lines of enamel, generally, on the grinding-surface of the upper molars of *Equus arcidens*, are less interrupted by folds and waves than in most *Equidæ*, showing in this respect the opposite extreme to those in the extinct *Equus plicidens*, Ow.*, of European postpliocene beds. But the most conspicuous and readily appreciable character of the present teeth from the postpliocene (?) beds of Paysandi is the greater degree of longitudinal curvature of the entire tooth (Plate LXII. figs. 3, 7), the molars retaining the generic Equine character in the length of the crown before it becomes divided into roots.

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* History of British Fossil Mammals, 8vo, 1846, p. 393, fig. 153.

Owing to the non-production of the fore part of the lobe *m* (figs. 1, 4 & 5, Plate LXII.) the groove *r* (ib. ib.) is less marked, and appears on the inner concave surface (fig. 2) rather than on the fore and flattened surface of the tooth as in *E. caballus* and *E. curvidens* (fig. 16).

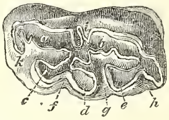
The longitudinal groove, *e*, on the concave inner surface (fig. 2), at the entry of the enamel-fold (fig. 1, *e*), is nearer the middle of that surface, as in *Equus principalis*, Ld., and is less near the posterior angle than in other Equines; and there is no groove answering to the middle of the inner surface of the process *m*, which process is there more or less indented in most other Equines. On the outer or convex surface (Plate LXII. fig. 6) the simplicity, narrowness, almost sharpness of the produced mid ridge, *h*, adds a differential character to the great longitudinal convexity of that surface in *Equus arcidens*. The posterior surface (fig. 3) is slightly concave from within outwards, shows a feeble indication of the entry of the fold *g*, and, owing to the minor production of the external angle, a greater proportion of the posterior longitudinal channel, *f*, is visible, looking at the back part of the tooth, than in other Equines.

The upper molar tooth representing the *Equus neogæus* of Lund (*op. cit.*, IV. tab. xlix. fig. 3) indicates a species as much smaller than *Equus arcidens* as is the Ass than the Horse. It is determined by that acute and careful observer as being the fourth molar of the right upper jaw (Fjerde Kindtand i hoïre Overkjæve, *tom. cit.* p. 93); it answers very nearly to the true molar which, in *Equus arcidens*, is represented in fig. 5, Plate LXII. By reference to the copy of Lund's figure in fig. 9 of this Plate, it appears that the lobe *c* extends, in *E. neogæus*, nearer to the antinternal angle, and communicates, through attrition, with the dentine of lobe *d*: the posterior surface of the tooth is, likewise, relatively narrower, the lobule *o* smaller, and the entering fold *g* shallower. These differences, with that of size, and in the absence of any knowledge of the degree of general curvature of the entire molar, forbid a reference of *Equus arcidens* to *E. neogæus*.

The *Equus principalis*, Ld., is represented by an upper molar indicative of a horse of equal size with *Equus arcidens*. The fossil molar tooth from the older breccia of the Brazilian cavern, figured in tab. xlix. fig. i. *tom. cit.* (copied in fig. 10, Plate LXII.), is determined by Lund to be the fifth molar of the right upper jaw, $=m\,2$ ("Femte Kindtand i hoïre Overkjæve," p. 93). It cannot be either the first, $p\,2$, or the last, $m\,3$, of the series; yet it differs more from the ordinary shape of the grinding-surface of the Equine molars, well preserved in *E. arcidens*, than do either of those modified molars at the two extremes of the series. The molar representing Lund's *Equus principalis* offers an interesting and suggestive resemblance to the upper molars of *Palæotherium* and to some teeth of species of *Rhinoceros*, in the contraction of the crown toward the inner surface, whereby the ordinary subquadrate form of the section of the upper Equine molar (as shown in all the figures illustrative of the present and preceding Papers) is exchanged for a subtriangular form, with the inner angle obtusely rounded off. Nevertheless all the characters indicated by letters in the figures above-cited, especially fig. 9, are present in *E. principalis*, Ld. The terminal lobules, *m*, *o*, of the lobes *c*, *d* are equal and parallel in position, as in *Palæotherium*; the fold *g*, as in *E. neogæus*, is less deep than in *E. arcidens*; the posterior ridge bounding the posterior outer longitudinal channel, *f'*, is not developed in *E. principalis* (at least in the representative molar of that species). The more important differences above defined are so well marked in this tooth as to lead to the inference that they would more or less characterize the whole upper molar series. Whether, or in what degree, the entire tooth was curved is not known.

I regret that I have no specimen of the lower molars of *Equus arcidens*. Dr. LUND figures the grinding-surface of the second true molar, left side, under jaw, of his *E. neogæus* (*tom. cit.*, IV. tab. xlix. fig. 5, copied in fig. 14, Plate LXII.), which shows as marked and interesting a departure from the pattern of the grinding-surface of these teeth in other Equines as does the upper molar. The external mid cleft (*i*) is deep and simple; and the outer surface of the two divisions of the molar (*a*, *b*) are regularly convex and to a degree corresponding with the concavities of the same part in the answering divisions of the upper molars, as shown in Plate LXII. fig. 9, at *f*, *f'*. The entering folds (fig. 14, *k*, *g*) at the inner side of the lower molar simply curve backward, do not expand terminally, and are wider at their beginning than in other Equines. There is barely a trace of the mid internal indent, *f*, fig. 4, of the *Equus fossilis*, from the Oreston Cavern (Cut, fig. 4), and in the figures of the Equine lower molars illustrative of the present Paper and its predecessor, and as in *E.* aff. *caballo* (=*E. curvidens*?, Plate LXII. fig. 15). Thus we have, in *E. neogæus*, as we most probably should have in *E. principalis* and *E. arcidens*, lower molars retaining more of the type of such teeth in *Palæotherium* and *Rhinoceros* than they do in ordinary recent and fossil Equines.

Fig. 4.



Lower molar, *p* 4,
Equus fossilis.

In my 'Odontography' I described and figured the molar series of the left ramus of a lower jaw, found fossil in the Pampas Deposits at Buenos Ayres, as being of a *Macrauchenia*, from the indications of the affinity of that genus to the perissodactyle section of CUVIER'S Pachyderms which had been detailed in the first account of that singular genus*. The subsequent discoveries of M. BRAVARD of parts of *Macrauchenia*, including the entire skull and dentition, confirmed the accuracy of that determination of the lower molars and of the generic distinction of the extinct animal.

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* "In the ungulate series there are but two known genera (the *Rhinoceros* and *Palæotherium*) which, like the quadruped in question, have only three toes on the fore foot. Again, in referring the *Macrauchenia* to the tridactyle family of Pachyderms, we find towards the close of our analysis, and by a detailed comparison of individual bones, that the *Macrauchenia* has the closest affinity to the *Palæotherium*. But the *Palæotherium*, like the *Rhinoceros* and *Tapir*, has the ulna distinct from the radius, and the fibula from the tibia; so that even if the Parisian Pachyderm had actually presented the same peculiarities of the cervical vertebræ as the Patagonian one, it would have been hazardous, to say the least, while ignorant of the dentition of the latter, to refer it to the genus *Palæotherium*. Most interesting, indeed, will be the knowledge, whenever the means of obtaining it may arrive, of the structure of the skull and teeth in the *Macrauchenia*."—*The Zoology of the Voyage of H.M.S. 'Beagle,'* Part I., Fossil Mammalia, 4to, 1840, p. 54, pls. vi.–xv.

I have given, in Plate LXII. fig. 13, a view of the grinding-surface of the second true molar of the *Macrauchenia* in the British Museum, of the natural size ; the reduced figure in the 'Odontography' may have suggested to Dr. LUND the idea of its being the same animal as his *Equus principalis* (see above, p. 561). The degree of resemblance is, however, not greater than both figs. 13 & 14, Plate LXII. offer to the corresponding teeth of *Palæotherium** and *Paloplotherium*†, at a similar degree of abrasion.

In the upper molars of *Macrauchenia* we find an interesting transitional modification between the generic pattern of the grinding-surface of the American extinct Equines (*E. neogæus*, *E. principalis*, *E. arcidens*) and that in *Nesodon*. The outer surface of the crown is impressed by two wide and moderately deep longitudinal channels, more angular as in *Palæotherium* than rounded as in *Equus*; a pair of depressions, answering to those marked *h* and *i* in *Equus*, appear to be shallower, are sooner blended together and obliterated. Three enamel-folds penetrate the inner side of the tooth, answering to those marked *r*, *e*, *g* in *Equus*, the middle one, *e*, also extending the furthest; but all these are shallower, save at their blind terminations, which consequently remain in the partially abraded crown as distinct islands of enamel including cement, and thus produce a characteristic resemblance to the dental pattern in *Nesodon*. The upper molars of *Nesodon*‡ differ from those of *Macrauchenia* in the crown being longer and transversely narrower; the outer longitudinal ridge is near the anterior border, not at the middle of that border; the inner border is penetrated by two enamel-folds, of which the anterior is bifurcate or three-branched; and the extremities of the folds, when insulated by wear, are nearer the outer border of the tooth.

The lower molars of *Nesodon*§ differ from those of *Macrauchenia* in the crowns being longer and transversely narrower; the outer longitudinal groove is nearer the anterior border; the anterior inner fold penetrates a plane behind the outer groove, advancing obliquely forward to meet it. Besides the posterior fold there is an island, which, if originally a part of that fold, is, in the worn tooth figured, separated from it. The canines are small and subequal to the other teeth in both genera, but are implanted by a divided fang in *Macrauchenia*. The lower incisors have an imbricate or slightly overlapping arrangement in *Nesodon*.

The upper molars of *Macrauchenia*, in the proportion of their fore-and-aft to their transverse diameters, are intermediate between *Equus* and *Nesodon*, but nearer the former. The high or backward position of the external nostrils in *Macrauchenia* is significant evidence of its affinity to *Toxodon*; and it may be that *Nesodon* shows more of this character than the fragment of skull on which the genus was founded led me to discern‖.

Howsoever this may prove to be, the additional evidence which has been obtained

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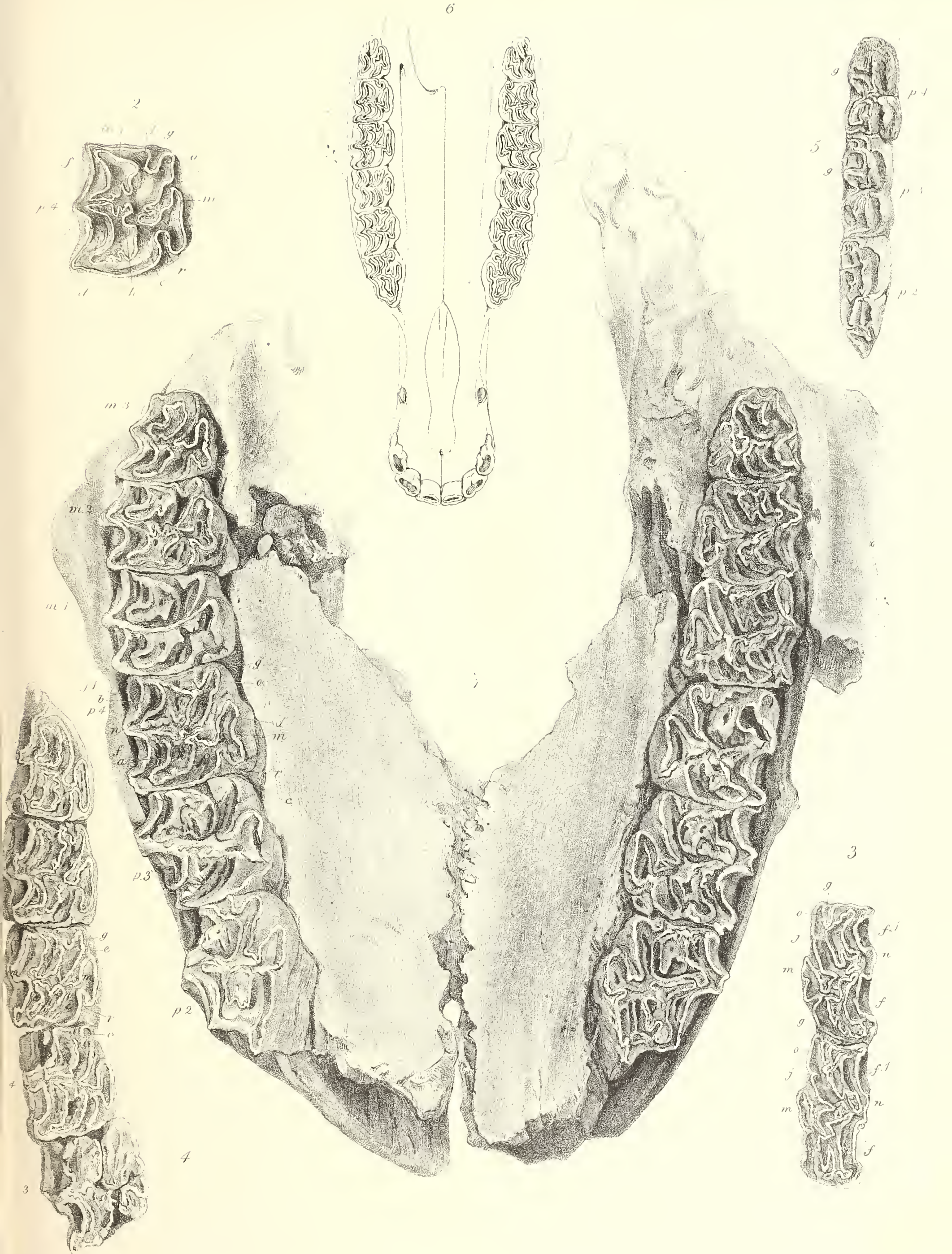
* Ossemens Fossiles, 4to, t. iii. pl. i. fig. 3.

† Quarterly Journal of Geological Society, vol. iv. pl. iv. fig. 3.

‡ Philosophical Transactions (1853), Pl. XVII. fig. 10.

§ Ibid. fig. 14.

‖ Philosophical Transactions (1853), Pl. XV. figs. 1 & 2.



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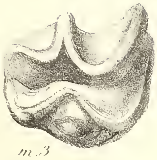

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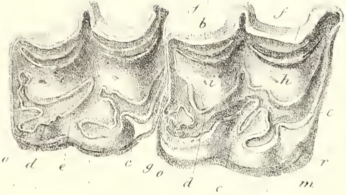

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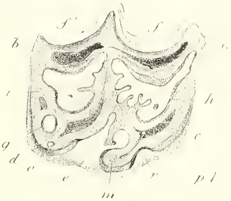

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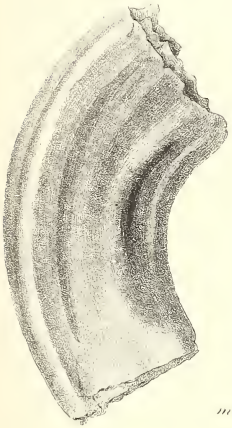

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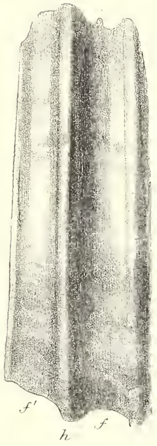

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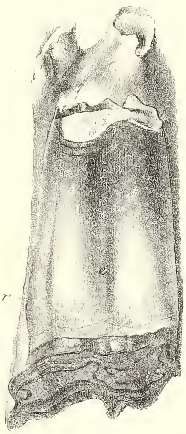

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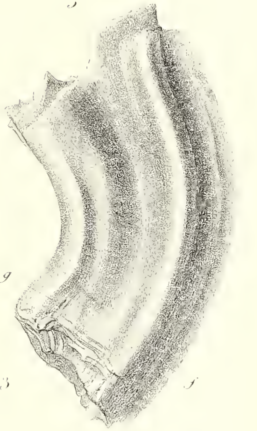

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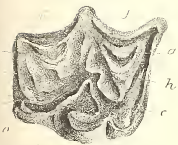

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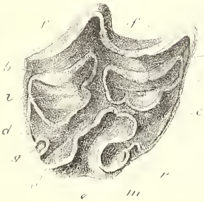

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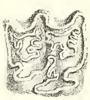

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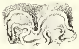

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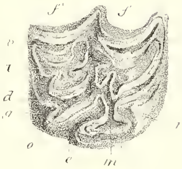

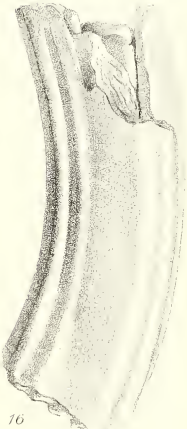
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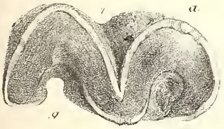

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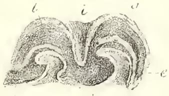

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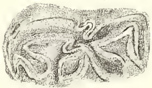

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XVIII. THE BAKERIAN LECTURE.—*On the Continuity of the Gaseous and Liquid States of Matter. By* THOMAS ANDREWS, *M.D., F.R.S., Vice-President of Queen's College, Belfast.*

Received June 14,—Read June 17, 1869.

IN 1822 M. CAGNIARD DE LA TOUR observed that certain liquids, such as ether, alcohol, and water, when heated in hermetically sealed glass tubes, became apparently reduced to vapour in a space from twice to four times the original volume of the liquid. He also made a few numerical determinations of the pressures exerted in these experiments[*]. In the following year FARADAY succeeded in liquefying, by the aid of pressure alone, chlorine and several other bodies known before only in the gaseous form[†]. A few years later THILORIER obtained solid carbonic acid, and observed that the coefficient of expansion of the liquid for heat is greater than that of any aëriform body[‡]. A second memoir by FARADAY, published in 1826, greatly extended our knowledge of the effects of cold and pressure on gases[§]. REGNAULT has examined with care the absolute change of volume in a few gases when exposed to a pressure of twenty atmospheres, and POUILLET has made some observations on the same subject. The experiments of NATTERER have carried this inquiry to the enormous pressure of 2790 atmospheres; and although his method is not altogether free from objection, the results he obtained are valuable and deserve more attention than they have hitherto received[‖].

In 1861 a brief notice appeared of some of my early experiments in this direction. Oxygen, hydrogen, nitrogen, carbonic oxide, and nitric oxide were submitted to greater pressures than had previously been attained in glass tubes, and while under these pressures they were exposed to the cold of the carbonic acid and ether-bath. None of the gases exhibited any appearance of liquefaction, although reduced to less than $\frac{1}{500}$ of their ordinary volume by the combined action of cold and pressure[¶]. In the third edition of MILLER'S 'Chemical Physics,' published in 1863, a short account, derived from a private letter addressed by me to Dr. MILLER, appeared of some new results I had obtained, under certain fixed conditions of pressure and temperature, with carbonic acid. As these results constitute the foundation of the present investigation and have never been published in a separate form, I may perhaps be permitted to make the following extract from my original communication to Dr. MILLER. "On partially liquefying carbonic acid by pressure alone, and gradually raising at the same time the temperature to

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[*] Annales de Chimie, 2ème série, xxi. pp. 127 and 178; also xxii. p. 410.

[†] Philosophical Transactions for 1823, pp. 160–189.

[‡] Annales de Chimie, 2ème série, lx. pp. 427, 432.

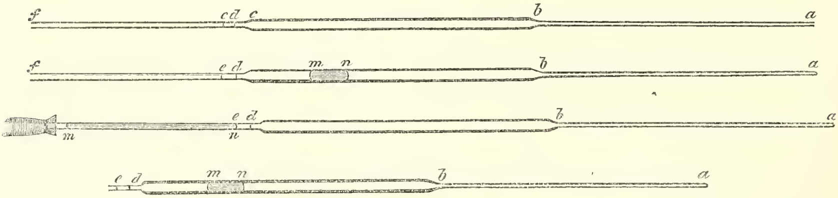
[§] Philosophical Transactions for 1845, p. 155.

[‖] POGGENDORFF'S 'Annalen,' xciv. p. 436.

[¶] Report of the British Association for 1861. Transactions of Sections, p. 76.

88° Fahr., the surface of demarcation between the liquid and gas became fainter, lost its curvature, and at last disappeared. The space was then occupied by a homogeneous fluid, which exhibited, when the pressure was suddenly diminished or the temperature slightly lowered, a peculiar appearance of moving or flickering striæ throughout its entire mass. At temperatures above 88° no apparent liquefaction of carbonic acid, or separation into two distinct forms of matter, could be effected, even when a pressure of 300 or 400 atmospheres was applied. Nitrous oxide gave analogous results"*.

The apparatus employed in this investigation is represented in Plate LXIII. It is shown in the simple form in which one gas only is exposed to pressure in figures 1 & 2. In figure 3 a section of the apparatus is given, and in figure 4 another section, with the arrangement for exposing the compressed gas to low degrees of cold *in vacuo.* In figures 5 and 6 a compound form of the same apparatus is represented, by means of which two gases may be simultaneously exposed to the same pressure. The gas to be compressed is introduced into a tube (*fa*) having a capillary bore from *a* to *b*, a diameter of about 2·5 millimetres from *b* to *c*, and of 1·25 millimetre from *c* to *f*. The gas carefully dried is passed for several hours through the tube open at both ends, as represented below.



The presence of a column of water of two metres in height was necessary to maintain a moderate stream of gas through the fine capillary tube. In the case of carbonic acid, the gas, after passing through the apparatus, was made to bubble by means of a connecting-tube through mercury, and a portion was collected from time to time, in order to ascertain its purity. The current was continued till the residual air, after the action of caustic potash, was reduced to a constant minimum. In repeated trials I found that in the complicated arrangements I had to adopt, the residual air could not be reduced to less than from $\frac{1}{500}$ to $\frac{1}{1000}$ of the entire volume of the carbonic acid. Even after continuing the current for twenty-four hours this residue appeared; and in discussing some of the results obtained by exposing the gas to high pressures, the presence of this small quantity of air must be carefully taken into account. The capillary end at *a* was then sealed, and the other end was also closed, and afterwards introduced under a surface of pure mercury contained in a glass capsule. The lower end, while under the surface of the mercury, was opened, and heat applied so as to expel a little of the gas. On cooling contraction occurred, and a short column of mercury entered. The capsule and lower end of the tube were then placed under the receiver of an air-pump, and a partial vacuum was formed till about one-fourth of the gas was removed. On restoring the pressure, a column of mercury entered and occupied the place of the expelled gas. By withdrawing the end of the tube from below the surface of the mercury in the capsule, and again exhausting cautiously, the column of mercury could be reduced to any required length. The tube, when thus filled, had the form shown (figure, p. 576).

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* Miller's 'Chemical Physics,' 3rd edition, p. 328.

Two file-marks had been made, one at *d*, the other at *e*, in the narrow part of the tube, about 10 millims. distant from each other, and the capacity of the tube from a mark near *a* to *d*, and also from the same mark to *e*, had been determined by filling it with mercury at a known temperature and weighing the mercury. The tube was now placed accurately in a horizontal position and connected by an air-tight junction with one limb of a long U-tube filled with mercury. Each limb of the U-tube was 600 millims. long, and 11 millims. in diameter. By removing mercury from the outer limb of the U-tube, a partial vacuum was obtained, and the column of mercury ($m\,n$) was drawn into the narrow tube ($d\,f$). From the difference of capacity of this part of the tube, the column of mercury was now about four times longer than before. It was easy with a little care so to adjust the pressure that the inner end of the mercurial column coincided with the mark *e*. When this was accomplished, the difference of level of the mercury in the two limbs of the U-tube was accurately read by means of a cathetometer, and the height of the barometer as well as the temperature were carefully noted. Similar observations were made with the gas expanded to the mark *d*. Two independent sets of data were thus obtained for calculating the volume of the gas at 0° C. and 760 millims., and the results usually agreed to less than $\frac{1}{1000}$ part. The tube, after being disconnected with the U-tube, was cut across a little beyond *e*, as shown (figure, p. 576), and was now ready to be introduced into the pressure apparatus.

The capillary tubes were calibrated with great care, and their mean capacity was determined by weighing a column of mercury whose length and position in the tube were accurately observed. One millim. of the air-tube used in these experiments had an average capacity of 0·00002477 cub. centim., and 1 millim. of the carbonic-acid-tube of 0·00003376 cub. centim. A table was constructed showing the corrected capacity of each capillary tube from the sealed end for every millimetre of its length. An allowance of 0·5 millim. was made for the cone formed in sealing the tube.

For the sake of clearness I have described these operations as if they were performed in the detached tube. In actual practice, the tube was in the brass end-piece before it was filled with gas (Plate LXIII. fig. 7).

The construction of the apparatus employed in these experiments will be readily understood from figures 3 and 4, Plate LXIII., which exhibit a section of the simple form. Two massive brass flanges are firmly attached round the ends of a cold-drawn copper tube of great strength, and by means of these flanges two brass end-pieces can be securely bolted to the ends of the copper tube, and the connexions made air-tight by the insertion of leather washers. The lower end-piece (fig. 7) carries a steel screw, 180 millims. long, 4 millims. in diameter, and with an interval of 0·5 millim. between each thread. The screw is packed with care, and readily holds a pressure of 400 atmospheres or more. A similar end-piece attached to the upper flange carries the glass tube containing the gas to be compressed (fig. 7). The apparatus, before being screwed up, is filled with water, and the pressure is obtained by screwing the steel screw into the water*.

In the compound apparatus (figs. 5 & 6) the internal arrangements are the same as in the simple form. A communication is established between the two sides of the apparatus through *a b*. It is indifferent which of the steel screws below is turned, as the pressure is immediately diffused through the interior of both copper tubes, and is applied through the moveable columns of mercury to the two gases to be compressed. Two screws are employed for the purpose of giving a greater command of pressure. In fig. 5 the apparatus is represented without any accessories. In fig. 6 the same apparatus is shown with the arrangements for maintaining the capillary tubes and the body of the apparatus itself at fixed temperatures. A rectangular brass case, closed before and behind with plate glass, surrounds each capillary tube, and allows it to be maintained at any required temperature by the flow of a stream of water. In the figure, the arrangement for obtaining a current of heated water in the case of the carbonic-acid tube is shown. The body of the apparatus itself, as is shown in the figure, is enclosed in an external vessel of copper, which is filled with water at the temperature of the apartment. This latter arrrangement is essential when accurate observations are made.

The temperature of the water surrounding the air-tube was made to coincide, as closely as possible, with that of the apartment, while the temperature of the water surrounding the carbonic-acid tube varied in different experiments from 13° C. to 48° C. In the experiments to be described in this communication, the mercury did not come into view in the capillary part of the air-tube till the pressure amounted to about forty atmospheres. The volumes of the air and of the carbonic acid were carefully read by a cathetometer, and the results could be relied on with certainty to less than 0·05 millim. The temperature of the water around the carbonic-acid tube was ascertained by a thermometer carefully graduated by myself according to an arbitrary scale. This thermometer was one of a set of four, which I constructed some years ago, and which all agreed so closely in their indications, that the differences were found to be altogether insignificant when their readings were reduced to degrees.

I have not attempted to deduce the actual pressure from the observed changes in the volume of the air in the air-tube. For this purpose it would be necessary to know with precision the deviations from the law of MARIOTTE exhibited by atmospheric air within the range of pressure employed in these experiments, and also the change of capacity in the capillary tube from internal pressure. In a future communication I hope to have an opportunity of considering this problem, which must be resolved rather by indirect than direct experiments. As regards the deviation of air from MARIOTTE'S law, it corresponds, according to the experiments of REGNAULT, to an apparent error of a little more than one-fourth of an atmosphere at a pressure of twenty atmospheres, and according to those of NATTERER, to an approximate error of one atmosphere when the pressure attains 107 atmospheres. These data are manifestly insufficient, and I have therefore not attempted to deduce the true pressure from the observed change of volume in the air-tube. It will be easy to apply hereafter the corrections for true pressure when they are ascertained, and for the purposes of this paper they are not required. The general form of the curves representing the changes of volume in carbonic acid will hardly undergo any sensible change from the irregularities in the air-tube; nor will any of the general conclusions at which I have arrived be affected by them. It must, however, always be understood that, when the pressures are occasionally spoken of, as indicated by the apparent contraction of the air in the air-gauge, the approximate pressures only are meant.

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* The first apparatus was constructed for me by Mr. J. CUMINE, of Belfast, to whose rare mechanical skill and valuable suggestions I have been greatly indebted in the whole course of this difficult investigation.

To obtain the capacity in cubic centimetres from the weight in grammes of the mercury which filled any part of a glass tube, the following formula was used,

$$C=W\,.\,\frac{1+0\cdot000154\,.\,t}{13\cdot596}\,.\,1\cdot00012,$$

where C is the capacity in cubic centims., W the weight of the mercury which filled the tube at the temperature t, 0·000154 the coefficient of apparent expansion of mercury in glass, 13·596 the density of mercury at 0°, and 1·00012 the density of water at 4°.

The volume of the gas V, at 0° and 760 millims. of pressure, was deduced from the double observations, as follows,

$$V=C\,.\,\frac{1}{1+\alpha t}\,.\,\frac{h-d}{760},$$

where C is the capacity of the tube (figure, page 576) from a to d, or from a to e, t the temperature, α the coefficient of expansion of the gas for heat (0·00366 in the case of air, 0·0037 in that of carbonic acid), h the height of the barometer reduced to 0° and to the latitude of 45°, d the difference of the mercurial columns in the U-tube similarly reduced.

Having thus ascertained the volumes of the air and of the carbonic acid before compression, at 0° and 760 millims., it was easy to calculate their volumes, under the same pressure of 760 millims., at the temperatures at which the measurements were made when the gases were compressed, and thence to deduce the values of the fractions representing the diminution of volume. But the fractions thus obtained would not give results directly comparable for air and carbonic acid. Although the capillary glass tubes in the apparatus (fig. 6) communicated with the same reservoir, the pressure on the contained gases was not quite equal, in consequence of the mercurial columns, which confined the air and carbonic acid, being of different heights. The column always stood higher in the carbonic-acid-tube than in the air-tube, so that the pressure in the latter was a little greater than in the former. The difference in the lengths of the mercurial columns rarely exceeded 200 millims., or about one-fourth of an atmosphere. This correction was always applied, as was also a trifling correction of 7 millims. for a difference of capillary depression in the two tubes.

In order to show more clearly the methods of reduction, I will give the details of one experiment.

Volume of air at 0° and 760 millims. calculated from the observations when the air was expanded to *a e*, 0·3124 cub. centim.

Volume of same air calculated from the observations when the air was expanded to *a d*, 0·3122 cub. centim.

Mean volume of air at 0° and 760 millims., 0·3123 cub. centim.

The volumes of the carbonic acid, deduced in like manner from two independent observations, were 0·3096 cub. centim. and 0·3094 cub. centim. Mean 0·3095 cub. centim.

The length of the column of air after compression, at 10°·76, in the capillary air-tube was 272·9 millims., corresponding to 0·006757 cub. centim. Hence we have

$$\delta'=\frac{0·006757}{0·3123\times 1·0394}=\frac{1}{48·04}.$$

But as the difference in the heights of the mercurial columns in the air-tube and carbonic-acid-tube, after allowing for the difference of capillary depression, was 178 millims., this result requires a further correction ($\frac{178}{760}$ of an atmosphere), in order to render it comparable with the compression in the carbonic-acid-tube. The final value for δ, the fraction representing the ratio of the volume of the compressed air at the temperature of the experiment to its volume at the same temperature and under the pressure of one atmosphere, will be

$$\delta=\frac{1}{47·81}.$$

The corresponding length of the carbonic acid at 13°·22, in its capillary tube, was 124·6 millims., equivalent to 0·004211 cub. centim., from which we deduce for the corresponding fraction for the carbonic acid

$$\varepsilon=\frac{0·004211}{0·3095\times 1·0489}=\frac{1}{77·09}.$$

Hence it follows that the same pressure, which reduced a given volume of air at 10°·76 to $\frac{1}{47·81}$ of its volume at the same temperature under one atmosphere, reduced carbonic acid at 13°·22 to $\frac{1}{77·09}$ of its volume at the temperature of 13°·22, and under a pressure of one atmosphere. Or assuming the compression of the air to be approximately a measure of the pressure, we may state that under a pressure of about 47·8 atmospheres carbonic acid at 13°·22 contracts to $\frac{1}{77·09}$ of its volume under one atmosphere.

In the following Tables, δ is the fraction representing the ratio of the volumes of the air after and before compression to one another, ε the corresponding fraction for the carbonic acid, t and t' the temperatures of the air and carbonic acid respectively, l the number of volumes which 17,000 volumes of carbonic acid, measured at 0° and 760 millims., would occupy at the temperature at which the observation was made under the pressure indicated by the air in the air-tube. The values of l are the ordinates of the curve lines shown in the figure, page 583*.

TABLE I.—Carbonic Acid at 13°·1.

δ.	t.	ε.	t'.	l.
$\frac{1}{47\cdot50}$	10°·75	$\frac{1}{76\cdot16}$	13°·18	234·1
$\frac{1}{48\cdot76}$	10·86	$\frac{1}{80\cdot43}$	13·18	221·7
$\frac{1}{48\cdot89}$	10·86	$\frac{1}{80\cdot90}$	13·09	220·3
$\frac{1}{49\cdot00}$	10·86	$\frac{1}{105\cdot9}$	13·09	168·2
$\frac{1}{49\cdot08}$	10·86	$\frac{1}{142\cdot0}$	13·09	125·5
$\frac{1}{49\cdot15}$	10·86	$\frac{1}{192\cdot3}$	13·09	92·7
$\frac{1}{49\cdot28}$	10·86	$\frac{1}{268\cdot8}$	13·09	66·3
$\frac{1}{49\cdot45}$	10·86	$\frac{1}{342\cdot8}$	13·09	52·0
$\frac{1}{49\cdot63}$	10·86	$\frac{1}{384\cdot9}$	13·09	46·3
$\frac{1}{50\cdot15}$	10·86	$\frac{1}{462\cdot9}$	13·09	38·5
$\frac{1}{50\cdot38}$	10·86	$\frac{1}{471\cdot5}$	13·09	37·8
$\frac{1}{54\cdot56}$	10·86	$\frac{1}{480\cdot4}$	13·09	37·1
$\frac{1}{75\cdot61}$	10·86	$\frac{1}{500\cdot7}$	13·09	35·6
$\frac{1}{90\cdot43}$	10·86	$\frac{1}{510\cdot7}$	13·09	34·9

It will be observed that at the pressure of 48·89 atmospheres, as measured by the contraction of the air in the air-tube, liquefaction began. This point could not be fixed by direct observation, inasmuch as the smallest visible quantity of liquid represented a column of gas at least 2 or 3 millims. in length. It was, however, determined indirectly by observing the volume of the gas 0°·2 or 0°·3 above the point of liquefaction, and calculating the contraction the gas would sustain in cooling down to the temperature at which liquefaction began. A slight increase of pressure, it will be seen, was required even in the early stages to carry on the process. Thus the air-guage, after all reductions

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* As l is the entire volume to which the carbonic acid is reduced, it does not always refer to homogeneous matter, but sometimes to a mixture of gas and liquid. Its value in the example given in the text is obtained as follows :—

$$l=17000\,.\frac{0\cdot004211}{0\cdot3095}=231\cdot3.$$

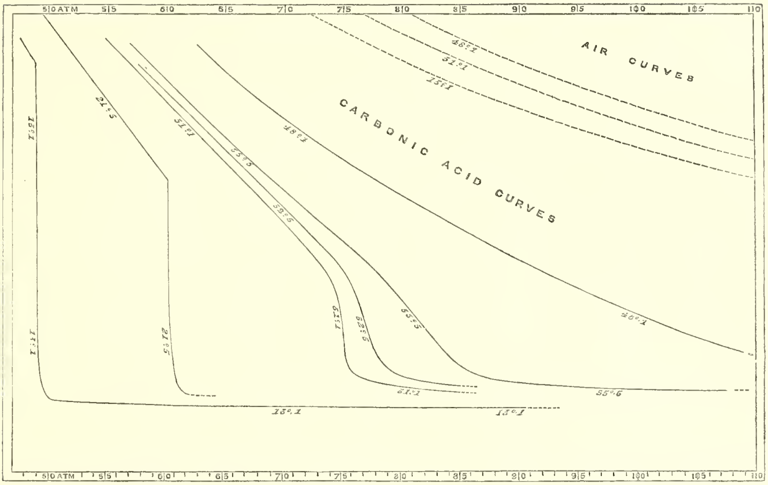
When l is homogeneous, $\frac{1}{\varepsilon}$ represents the density of the carbonic acid referred to carbonic acid gas, at the temperature t', and under a pressure of one atmosphere.

were made, indicated an increase of pressure of about one-fourth of an atmosphere (from 48·89 to 49·15 atmospheres) during the condensation of the first and second thirds of the carbonic acid. According to theory no change of volume ought to have occurred. This apparent anomaly is explained by the presence of the trace of air (about $\frac{1}{500}$ part) in the carbonic acid to which I before referred. It is easy to see that the increase of pressure shown in these experiments is explained by the presence of this small quantity of air. If a given volume of carbonic acid contain $\frac{1}{500}$ of air, that air will be diffused through a space 500 times greater than if the same quantity of air were in a separate state. Compress the mixture till 50 atmospheres of pressure have been applied, and the air will now occupy, or be diffused through, ten times the space it would occupy if alone and under the pressure of one atmosphere; or it will be diffused through the space it would occupy, if alone and under the pressure of $\frac{1}{10}$ of an atmosphere. While the carbonic acid is liquefying, pressure must be applied in order to condense this air; and to reduce it to one-half its volume, an increase of $\frac{1}{10}$ of an atmosphere is required. The actual results obtained by experiment approximate to this calculation. From similar considerations, it follows that if a mixture of air and carbonic acid be taken, for example in equal volumes, the pressure, after liquefaction has begun, must be augmented by several atmospheres, in order to liquefy the whole of the carbonic acid. Direct experiments have shown this conclusion to be true.

The small quantity of air in the carbonic acid disturbed the liquefaction in a marked manner, when nearly the whole of the carbonic acid was liquefied, and when its volume relatively to that of the uncondensed carbonic acid was considerable. It resisted for some time absorption by the liquid, but on raising the pressure to 50·4 atmospheres it was entirely absorbed. If the carbonic acid had been absolutely pure, the part of the curve for 13°·1 (figure, page 583) representing the fall from the gaseous to the liquid state, would doubtless have been straight throughout its entire course, and parallel to the lines of equal pressure.

TABLE II.—Carbonic Acid at 21°·5.

δ.	t.	ε.	t'.	l.
$\frac{1}{46\cdot70}$	8°·63	$\frac{1}{67\cdot26}$	21°·46	272·9
$\frac{1}{60\cdot05}$	8·70	$\frac{1}{114\cdot7}$	21·46	160·0
$\frac{1}{60\cdot29}$	8·70	$\frac{1}{174\cdot8}$	21·46	105·0
$\frac{1}{60\cdot55}$	8·70	$\frac{1}{240\cdot5}$	21·46	76·3
$\frac{1}{61\cdot00}$	8·70	$\frac{1}{367\cdot7}$	21·46	49·9
$\frac{1}{62\cdot21}$	8·70	$\frac{1}{440\cdot0}$	21·46	41·7
$\frac{1}{62\cdot50}$	8·70	$\frac{1}{443\cdot3}$	21·46	41·4



The curve representing the results at 21°·5 agrees in general form with that for 13°·1, as shown in the above figure. At 13°·1, under a pressure of about 49 atmospheres, the volume of carbonic acid is little more than three-fifths of that which a perfect gas would occupy under the same conditions. After liquefaction carbonic acid yields to pressure much more than ordinary liquids; and the compressibility appears to diminish as the pressure increases. The high rate of expansion by heat of liquid carbonic acid, first noticed by Thilorier, is fully confirmed by this investigation.

The next series of experiments was made at the temperature of 31°·1, or 0°·2 above the point at which, by compression alone, carbonic acid is capable of assuming visibly the liquid form. Since I first announced this fact in 1863, I have made careful experiments to fix precisely the temperature of this critical point in the case of carbonic acid. It was found in three trials to be 30°·92 C., or 87°·7 Fahr. Although for a few degrees above this temperature a rapid fall takes place from increase of pressure, when the gas is reduced to the volume at which it might be expected to liquefy, no separation of the carbonic acid into two distinct conditions of matter occurs, so far as any indication of such a separation is afforded by the action of light. By varying the pressure or temperature, but always keeping the latter above 30°·92, the great changes of density which occur about this point produce the flickering movements I formerly described, resembling in an exaggerated form the appearances exhibited during the mixture of liquids of different densities, or when columns of heated air ascend through colder strata. It is easy so to adjust the pressure that one-half of the tube shall be filled with uncondensed gas and one-half with the condensed liquid. Below the critical temperature this distinction is easily seen to have taken place, from the visible surface of demarcation between the liquid and gas, and from the shifting at the same surface of the image of any perpendicular line placed behind the tube. But above 30°·92 no such appearances are seen, and the most careful examination fails to discover any heterogeneity in the carbonic acid, as it exists in the tube.

TABLE III.—Carbonic Acid at 31°·1.

δ.	t.	ε.	t′.	l.
$\frac{1}{54\cdot79}$	11°·59	$\frac{1}{80\cdot55}$	31°·17	235·4
$\frac{1}{55\cdot96}$	11·59	$\frac{1}{83\cdot39}$	31·22	227·4
$\frac{1}{57\cdot18}$	11·58	$\frac{1}{86\cdot58}$	31·15	219·0
$\frac{1}{58\cdot46}$	11·55	$\frac{1}{90\cdot04}$	31·19	210·6
$\frac{1}{59\cdot77}$	11·41	$\frac{1}{93\cdot86}$	31·18	202·0
$\frac{1}{61\cdot18}$	11·40	$\frac{1}{98\cdot07}$	31·20	193·3
$\frac{1}{62\cdot67}$	11·44	$\frac{1}{103\cdot1}$	31·19	183·9
$\frac{1}{64\cdot27}$	11·76	$\frac{1}{109\cdot6}$	31·13	173·0
$\frac{1}{65\cdot90}$	11·73	$\frac{1}{116\cdot2}$	31·19	163·2
$\frac{1}{67\cdot60}$	11·63	$\frac{1}{124\cdot4}$	31·15	152·4
$\frac{1}{69\cdot39}$	11·55	$\frac{1}{134\cdot5}$	31·03	140·9
$\frac{1}{71\cdot25}$	11·40	$\frac{1}{147\cdot8}$	31·06	128·2
$\frac{1}{73\cdot26}$	11·45	$\frac{1}{169\cdot0}$	31·09	112·2
$\frac{1}{73\cdot83}$	13·00	$\frac{1}{174\cdot4}$	31·08	108·7
$\frac{1}{75\cdot40}$	11·62	$\frac{1}{311\cdot1}$	31·06	60·9
$\frac{1}{77\cdot64}$	11·65	$\frac{1}{369\cdot1}$	31·06	51·3
$\frac{1}{79\cdot92}$	11·16	$\frac{1}{383\cdot0}$	31·10	49·4
$\frac{1}{82\cdot44}$	11·23	$\frac{1}{395\cdot7}$	31·07	47·9
$\frac{1}{85\cdot19}$	11·45	$\frac{1}{405\cdot5}$	31·05	46·7

The graphical representation of these experiments, as shown in the preceding page, exhibits some marked differences from the curves for lower temperatures. The dotted lines in the figure represent a portion of the curves of a perfect gas (assumed to have the same volume at 0° and under one atmosphere as the carbonic acid) for the temperatures of 13°·1, 31°·1, and 48°·1. The volume of the carbonic acid at 31°·1, it will be observed, diminishes with tolerable regularity, but much faster than according to the law of MARIOTTE, till a pressure of about 73 atmospheres is attained. The diminution of volume then goes on very rapidly, a reduction to nearly one-half taking place, when the pressure is increased from 73 to 75 atmospheres, or only by $\frac{1}{37}$ of the whole pressure. The fall is not, however, abrupt as in the case of the formation of the liquid at lower temperatures, but a steady increase of pressure is required to carry it through. During this fall, as has already been stated, there is no indication at any stage of the process of two conditions of matter being present in the tube. Beyond 77 atmospheres carbonic acid at 31°·1 yielded much less than before to pressure, its volume having become reduced nearly to that which it ought to occupy as a liquid at the temperature at which the observations were made.

Table IV.—Carbonic Acid at 32°·5.

δ.	t.	ε.	t'.	l.
$\frac{1}{57{\cdot}38}$	12°·10	$\frac{1}{85{\cdot}90}$	32°·50	221·7
$\frac{1}{71{\cdot}52}$	12·15	$\frac{1}{140{\cdot}3}$	32·34	135·6
$\frac{1}{73{\cdot}60}$	12·30	$\frac{1}{156{\cdot}0}$	32·45	122·0
$\frac{1}{74{\cdot}02}$	12·30	$\frac{1}{159{\cdot}9}$	32·46	119·1
$\frac{1}{76{\cdot}25}$	12·40	$\frac{1}{191{\cdot}7}$	32·38	99·3
$\frac{1}{78{\cdot}52}$	12·50	$\frac{1}{311{\cdot}8}$	32·48	61·1
$\frac{1}{79{\cdot}77}$	12·35	$\frac{1}{351{\cdot}3}$	32·54	54·2
$\frac{1}{84{\cdot}90}$	12·35	$\frac{1}{387{\cdot}8}$	32·75	49·1

Table V.—Carbonic Acid at 35°·5.

δ.	t.	ε.	t'.	l.
$\frac{1}{56{\cdot}80}$	15°·68	$\frac{1}{82{\cdot}72}$	35°·49	232·5
$\frac{1}{59{\cdot}34}$	15·70	$\frac{1}{88{\cdot}94}$	35·54	216·2
$\frac{1}{62{\cdot}15}$	15·66	$\frac{1}{96{\cdot}41}$	35·52	199·5
$\frac{1}{65{\cdot}23}$	15·66	$\frac{1}{106{\cdot}0}$	35·51	181·4
$\frac{1}{68{\cdot}66}$	15·75	$\frac{1}{118{\cdot}4}$	35·47	162·4
$\frac{1}{72{\cdot}45}$	15·79	$\frac{1}{135{\cdot}1}$	35·48	142·3
$\frac{1}{76{\cdot}58}$	15·52	$\frac{1}{161{\cdot}2}$	35·55	119·3
$\frac{1}{81{\cdot}28}$	15·61	$\frac{1}{228{\cdot}0}$	35·55	84·4
$\frac{1}{86{\cdot}60}$	15·67	$\frac{1}{351{\cdot}9}$	35·48	54·6
$\frac{1}{89{\cdot}52}$	15·67	$\frac{1}{373{\cdot}7}$	35·50	51·5
$\frac{1}{92{\cdot}64}$	15·64	$\frac{1}{387{\cdot}9}$	35·61	49·6
$\frac{1}{99{\cdot}57}$	15·61	$\frac{1}{411{\cdot}0}$	35·55	46·8
$\frac{1}{107\ 6}$	15·47	$\frac{1}{430{\cdot}2}$	35·53	44·7

Table VI.—Carbonic Acid at 48°·1.

δ.	t.	ε.	t′.	l.
$\frac{1}{62\cdot60}$	15°·67	$\frac{1}{86\cdot45}$	47°·95	231·5
$\frac{1}{68\cdot46}$	15·79	$\frac{1}{99\cdot39}$	48·05	201·4
$\frac{1}{75\cdot58}$	15·87	$\frac{1}{117\cdot8}$	48·12	170·0
$\frac{1}{84\cdot35}$	15·91	$\frac{1}{146\cdot8}$	48·25	136·5
$\frac{1}{95\cdot19}$	15·83	$\frac{1}{198\cdot5}$	48·13	100·8
$\frac{1}{109\cdot4}$	16·23	$\frac{1}{298\cdot4}$	48·25	67·2

The curve for 32°·5 (page 583) resembles closely that for 31°·1. The fall is, however, less abrupt than at the latter temperature. The range of pressure in the experiments at 35°·5 extends from 57 to above 107 atmospheres. The fall is here greatly diminished, and it has nearly lost its abrupt character. It is most considerable from 76 to 87 atmospheres, where an increase of one-seventh in the pressure produces a reduction of volume to one-half. At 107 atmospheres the volume of the carbonic acid has come almost into conformity with that which it should occupy, if it were derived directly from liquid carbonic acid, according to the law of the expansion of that body for heat.

The curve for 48°·1 is very interesting. The fall shown in the curves for lower temperatures has almost, if not altogether, disappeared, and the curve itself approximates to that which would represent the change of volume in a perfect gas. At the same time the contraction is much greater than it would have been if the law of Mariotte had held good at this temperature. Under a pressure of 109 atmospheres, the carbonic acid is rapidly approaching to the volume it would occupy if derived from the expansion of the liquid; and if the experiment had not been interrupted by the bursting of one of the tubes, it would doubtless have fallen into position at a pressure of 120 or 130 atmospheres.

I have not made any measurements at higher temperatures than 48°·1; but it is clear that, as the temperature rises, the curve would continue to approach to that representing the change of volume of a perfect gas.

I have frequently exposed carbonic acid, without making precise measurements, to much higher pressures than any marked in the Tables, and have made it pass, without break or interruption from what is regarded by every one as the gaseous state, to what is, in like manner, universally regarded as the liquid state. Take, for example, a given volume of carbonic acid gas at 50° C., or at a higher temperature, and expose it to increasing pressure till 150 atmospheres have been reached. In this process its volume will steadily diminish as the pressure augments, and no sudden diminution of volume, without the application of external pressure, will occur at any stage of it. When the full pressure has been applied, let the temperature be allowed to fall till the carbonic acid has reached the ordinary temperature of the atmosphere. During the whole of this operation no breach of continuity has occurred. It begins with a gas, and by a series of gradual changes, presenting nowhere any abrupt alteration of volume or sudden evolution of heat, it ends with a liquid. The closest observation fails to discover anywhere indications of a change of condition in the carbonic acid, or evidence, at any period of the process, of part of it being in one physical state and part in another. That the gas has actually changed into a liquid would, indeed, never have been suspected, had it not shown itself to be so changed by entering into ebullition on the removal of the pressure. For convenience this process has been divided into two stages, the compression of the carbonic acid and its subsequent cooling; but these operations might have been performed simultaneously, if care were taken so to arrange the application of the pressure and the rate of cooling, that the pressure should not be less than 76 atmospheres when the carbonic acid had cooled to 31°.

We are now prepared for the consideration of the following important question. What is the condition of carbonic acid when it passes, at temperatures above 31°, from the gaseous state down to the volume of the liquid, without giving evidence at any part of the process of liquefaction having occurred? Does it continue in the gaseous state, or does it liquefy, or have we to deal with a new condition of matter? If the experiment were made at 100°, or at a higher temperature, when all indications of a fall had disappeared, the probable answer which would be given to this question is that the gas preserves its gaseous condition during the compression; and few would hesitate to declare this statement to be true, if the pressure, as in NATTERER's experiments, were applied to such gases as hydrogen or nitrogen. On the other hand, when the experiment is made with carbonic acid at temperatures a little above 31°, the great fall which occurs at one period of the process would lead to the conjecture that liquefaction had actually taken place, although optical tests carefully applied failed at any time to discover the presence of a liquid in contact with a gas. But against this view it may be urged with great force, that the fact of additional pressure being always required for a further diminution of volume, is opposed to the known laws which hold in the change of bodies from the gaseous to the liquid state. Besides, the higher the temperature at which the gas is compressed, the less the fall becomes, and at last it disappears.

The answer to the foregoing question, according to what appears to me to be the true interpretation of the experiments already described, is to be found in the close and intimate relations which subsist between the gaseous and liquid states of matter. The ordinary gaseous and ordinary liquid states are, in short, only widely separated forms of the same condition of matter, and may be made to pass into one another by a series of gradations so gentle that the passage shall nowhere present any interruption or breach of continuity. From carbonic acid as a perfect gas to carbonic acid as a perfect liquid, the transition we have seen may be accomplished by a continuous process, and the gas and liquid are only distant stages of a long series of continuous physical changes. Under certain conditions of temperature and pressure, carbonic acid finds itself, it is true, in what may be described as a state of instability, and suddenly passes, with the evolution of heat, and without the application of additional pressure or change of temperature, to the volume, which by the continuous process can only be reached through a long and circuitous route. In the abrupt change which here occurs, a marked difference is exhibited, while the process is going on, in the optical and other physical properties of the carbonic acid which has collapsed into the smaller volume, and of the carbonic acid not yet altered. There is no difficulty here, therefore, in distinguishing between the liquid and the gas. But in other cases the distinction cannot be made; and under many of the conditions I have described it would be vain to attempt to assign carbonic acid to the liquid rather than the gaseous state. Carbonic acid, at the temperature of 35°·5, and under a pressure of 108 atmospheres, is reduced to $\frac{1}{430}$ of the volume it occupied under a pressure of one atmosphere; but if any one ask whether it is now in the gaseous or liquid state, the question does not, I believe, admit of a positive reply. Carbonic acid at 35°·5, and under 108 atmospheres of pressure, stands nearly midway between the gas and the liquid; and we have no valid grounds for assigning it to the one form of matter any more than to the other. The same observation would apply with even greater force to the state in which carbonic acid exists at higher temperatures and under greater pressures than those just mentioned. In the original experiment of CAGNIARD DE LA TOUR, that distinguished physicist inferred that the liquid had disappeared, and had changed into a gas. A slight modification of the conditions of his experiment would have led him to the opposite conclusion, that what had been before a gas was changed into a liquid. These conditions are, in short, the intermediate states which matter assumes in passing, without sudden change of volume, or abrupt evolution of heat, from the ordinary liquid to the ordinary gaseous state.

In the foregoing observations I have avoided all reference to the molecular forces brought into play in these experiments. The resistance of liquids and gases to external pressure tending to produce a diminution of volume, proves the existence of an internal force of an expansive or resisting character. On the other hand, the sudden diminution of volume, without the application of additional pressure externally, which occurs when a gas is compressed, at any temperature below the critical point, to the volume at which liquefaction begins, can scarcely be explained without assuming that a molecular force of great attractive power comes here into operation, and overcomes the resistance to diminution of volume, which commonly requires the application of external force. When the passage from the gaseous to the liquid state is effected by the continuous process described in the foregoing pages, these molecular forces are so modified as to be unable at any stage of the process to overcome alone the resistance of the fluid to change of volume.

The properties described in this communication, as exhibited by carbonic acid, are not peculiar to it, but are generally true of all bodies which can be obtained as gases and liquids. Nitrous oxide, hydrochloric acid, ammonia, sulphuric ether, and sulphuret of carbon, all exhibited, at fixed pressures and temperatures, critical points, and rapid changes of volume with flickering movements when the temperature or pressure was changed in the neighbourhood of those points. The critical points of some of these bodies were above 100°; and in order to make the observations, it was necessary to bend the capillary tube before the commencement of the experiment, and to heat it in a bath of paraffin or oil of vitriol.

The distinction between a gas and vapour has hitherto been founded on principles which are altogether arbitrary. Ether in the state of gas is called a vapour, while sulphurous acid in the same state is called a gas; yet they are both vapours, the one derived from a liquid boiling at 35°, the other from a liquid boiling at —10°. The distinction is thus determined by the trivial condition of the boiling-point of the liquid, under the ordinary pressure of the atmosphere, being higher or lower than the ordinary temperature of the atmosphere. Such a distinction may have some advantages for practical reference, but it has no scientific value. The critical point of temperature affords a criterion for distinguishing a vapour from a gas, if it be considered important to maintain the distinction at all. Many of the properties of vapours depend on the gas and liquid being present in contact with one another; and this, we have seen, can only occur at temperatures below the critical point. We may accordingly define a vapour to be a gas at any temperature under its critical point. According to this definition, a vapour may, by pressure alone, be changed into a liquid, and may therefore exist in presence of its own liquid; while a gas cannot be liquefied by pressure—that is, so changed by pressure as to become a visible liquid distinguished by a surface of demarcation from the gas. If this definition be accepted, carbonic acid will be a vapour below 31°, a gas above that temperature; ether a vapour below 200°, a gas above that temperature.

We have seen that the gaseous and liquid states are only distant stages of the same condition of matter, and are capable of passing into one another by a process of continuous change. A problem of far greater difficulty yet remains to be solved, the possible continuity of the liquid and solid states of matter. The fine discovery made some years ago by James Thomson, of the influence of pressure on the temperature at which liquefaction occurs, and verified experimentally by Sir W. Thomson, points, as it appears to me, to the direction this inquiry must take; and in the case at least of those bodies which expand in liquefying, and whose melting-points are raised by pressure, the transition may possibly be effected. But this must be a subject for future investigation; and for the present I will not venture to go beyond the conclusion I have already drawn from direct experiment, that the gaseous and liquid forms of matter may be transformed into one another by a series of continuous and unbroken changes.

APPENDIX.

The following experiments, made at temperatures differing from any of the foregoing series, are added, as they may hereafter be useful for reference.

δ.	t.	ϵ.	t'.
$\frac{1}{48\cdot15}$	$1\overset{\circ}{2}\cdot42$	$\frac{1}{75\cdot00}$	$1\overset{\circ}{5}\cdot76$
$\frac{1}{53\cdot04}$	11·13	$\frac{1}{92\cdot53}$	16·45
$\frac{1}{47\cdot45}$	11·50	$\frac{1}{64\cdot14}$	31·91
$\frac{1}{71\cdot75}$	13·10	$\frac{1}{148\cdot5}$	31·65
$\frac{1}{73\cdot88}$	13·20	$\frac{1}{170\cdot5}$	31·71
$\frac{1}{73\cdot92}$	13·20	$\frac{1}{157\cdot9}$	33·15
$\frac{1}{73\cdot77}$	12·74	$\frac{1}{152\cdot3}$	33·58
$\frac{1}{73\cdot89}$	13·14	$\frac{1}{144\cdot5}$	35·00
$\frac{1}{73\cdot89}$	13·21	$\frac{1}{140\cdot0}$	36·03
$\frac{1}{76\cdot05}$	13·27	$\frac{1}{153\cdot4}$	36·05
$\frac{1}{78\cdot35}$	13·38	$\frac{1}{171\cdot1}$	36·11
$\frac{1}{80\cdot74}$	13·40	$\frac{1}{197\cdot8}$	36·22
$\frac{1}{83\cdot31}$	13·45	$\frac{1}{251\cdot4}$	36·20
$\frac{1}{86\cdot01}$	13·50	$\frac{1}{323\cdot6}$	36·08
$\frac{1}{88\cdot92}$	13·53	$\frac{1}{358\cdot1}$	36·18
$\frac{\ }{92\cdot06}$	13·55	$\frac{1}{377\cdot8}$	36·22

Fig. 1.

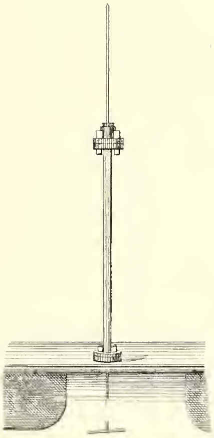


Fig. 2

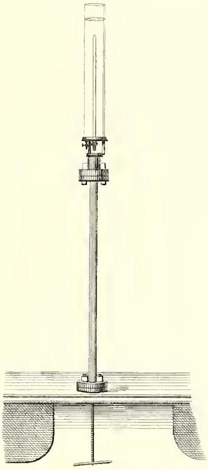


Fig. 3

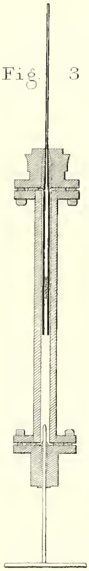


Fig. 4

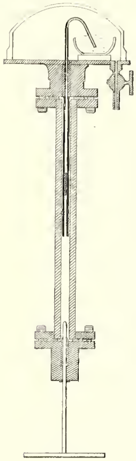


Fig. 5.

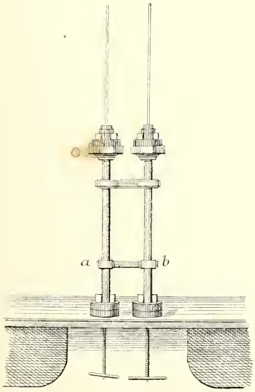


Fig. 6

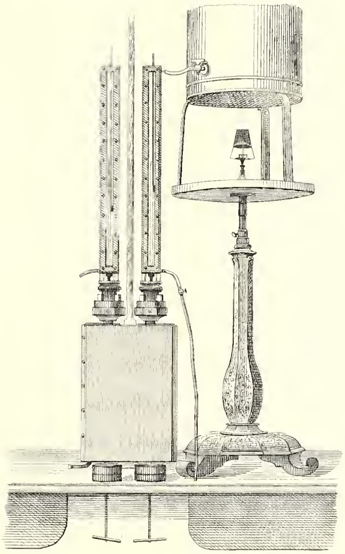
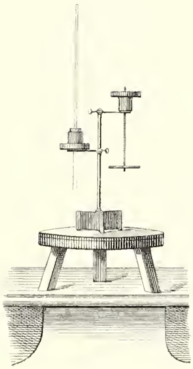


Fig. 7



BRITISH MUSEUM NATURAL HISTORY.

XIX. *On the Specific Heat and other Physical Characters of Mixtures of Ethylic Alcohol and Water.* *By* A. Dupré, *Ph.D., Lecturer on Chemistry at Westminster Hospital, and* F. J. M. Page, *B.Sc.* *Communicated by* Charles Brooke, *F.R.S.*

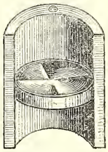
Received February 4,—Read March 11, 1869.

Section I.—*Specific Heat.*

The authors, having recently had occasion to estimate carefully the specific heat of mixtures of alcohol and water, came in the course of these experiments to the unexpected result that the specific heat of such mixtures, up to an alcoholic strength of about 36 per cent., is sensibly higher than the specific heat of water itself. These experiments, to the best of their knowledge, furnish the first example of a liquid having a higher specific heat than water, which has always been considered to possess the highest specific heat of any substance solid or liquid. They therefore beg leave to lay their results before the Royal Society.

Two methods were employed for the estimation of the specific heat. The first method, and the one chiefly used, consisted in heating a metallic weight to a certain temperature, and then plunging it into the liquid whose specific heat was to be estimated; the rise in temperature thus produced in different liquids will, after the necessary corrections, be inversely proportional to the specific heat of these liquids.

Fig. 1.



Annular weight and fan-wheel, half of the former being cut away to show the fan-wheel.

Two weights were employed, one of brass, the other copper gilt, both well polished. They were made in the shape of stout rings—the internal diameter of the brass weight being 38·5 millims., its external diameter 49 millims., its height 39·5 millims., its weight 246·49 grms.; the internal diameter of the copper ring was 39 millims., its external diameter 61 millims., its height 39·5 millims., and its weight 614·49 grms. In the inner cylindrical space of each was inserted a small fan-wheel, resembling in its construction the wheel of a smoke-jack, so that, when the heated weight is caused to rotate rapidly in a liquid, a current is thus drawn through the ring, producing, first, a very complete mixture of the liquid, and, secondly, a more rapid cooling of the weight.

The weights were heated in an apparatus exactly similar to that employed by Regnault in his researches on the specific heat of solids—steam, or the vapour of boiling alcohol being employed for heating them.

The liquid whose specific heat is to be estimated is carefully measured in a narrow-necked flask, and poured into a calorimeter of very thin polished brass, supported on stretched silk cords and surrounded by a double cylinder of tin plate, to prevent as far as possible any gain or loss by radiation.

A thermometer, divided into tenths of a degree Centigrade, allowing $\frac{1}{100}$ of a degree to be read, was used to indicate the temperature of the steam-oven.

Two thermometers were employed to indicate the temperature of the calorimeter,—one having a range from 10° to 20° C., and divided into twentieths of a degree Centigrade, allowing $\frac{1}{200}$ of a degree to be read off by means of a telescope; the other had a range from 16° to 21°·5 C., divided into fiftieths of a degree C. and allowing $\frac{1}{500}$ of a degree to be read off.

The bulbs of both these thermometers were thin, and of such a length as to pass through nearly the entire depth of liquid contained in the calorimeter. A thermometer similar to the two last was employed to take the temperature of the air. All the thermometers were carefully compared with a standard, as well as calibrated by thread measurements.

The experiments are conducted as follows. As soon as the temperature of the steam-oven remains constant for at least ten or fifteen minutes, it is read off; a measured quantity of the liquid, cooled a few degrees below the temperature of the room, is poured into the calorimeter, and its temperature, after thorough mixture, read off by means of a telescope. On a given signal, one assistant pushes the calorimeter underneath the steam-oven; a second then, opening the slide-valve, lets down the weight which is detached from the string, and the calorimeter is brought back into its first position. The weight, which has of course been kept underneath the surface of the liquid after leaving the steam-oven, and has not been allowed to touch the sides or bottom of the brass vessel, is now hooked to a strand of worsted, previously twisted; on allowing this to untwist a rapid rotation of the weight ensues, and consequently a thorough mixture of the liquid by the fan-wheel*. The whole of these movements occupy from fifteen to twenty-five seconds.

The elevation of the temperature of the calorimeter is observed, which usually reaches a maximum one minute after the introduction of the brass weight, whilst with the copper weight a minute and a half elapsed before this was effected.

As soon as the temperature has attained its greatest elevation and the thermometer begins to sink, the time is noted; and in half a minute with the brass weight, or three quarters of a minute with the copper weight, the temperature is again read off; the fall of temperature during this interval is added, as a correction, to the highest temperature observed, as representing the loss due to radiation. This correction usually amounts only to a few hundredths of a degree.

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* As a mean of several experiments, it was found that a rapid rotation of the weight during five minutes produced a rise in the temperature of the water in the calorimeter of 0°·005 C. In the course of an experiment on the specific heat of a mixture, the time during which the weight rotated at the above speed always fell short of one minute, consequently the effect thereby produced on the temperature of the calorimeter is somewhat less than 0°·001 C. The heat thus produced is moreover a nearly constant quantity, affecting all experiments alike, so that its ultimate influence on the specific heat of the various mixtures is reduced to an almost infinitesimal fraction; it has therefore been neglected throughout the calculations.

The following Tables give the results of the experiments.

t'' denotes temperature of air.

T denotes temperature of the steam-oven and consequently of the weight.

t denotes temperature of calorimeter at beginning.

t' denotes temperature of calorimeter at end.

v denotes loss of temperature during 30^s or 45^s.

e denotes total corrected rise in temperature.

N denotes the number of degrees expended by the heated weight in raising the liquid in the calorimeter one degree, the heat expended in raising the temperature of the calorimeter and immersed part of thermometer having been previously deducted.

This figure, N, will therefore be directly proportional to the specific heat of the various liquids used, supposing equal weights taken in each case.

Table I.

Brass ring, weight 264·49 grms.

Brass value of calorimeter and immersed part of thermometer 69·54 grms.

Quantity of liquid contained in calorimeter 449·53 cub. centims.

Time occupied in making each experiment, one minute.

a. Distilled Water.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
1.	9·0	97·80	10·048	14·142	0·020	4·096	20·14
2.	11·6	97·83	10·234	14·297	0·025	4·088	20·14
3.	12·1	97·90	10·568	14·654	0·005	4·081	20·11
4.	13·1	98·10	10·260	14·369	0·000	4·109	20·09

Mean value of N 20·12.

b. Spirit 10 per cent. Sp. gravity 0·9814.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
5.	12·4	97·50	10·522	14·505	0·000	3·983	20·92
6.	11·9	97·87	10·305	14·351	0·000	4·046	20·74
7.	13·9	98·20	11·593	15·586	0·000	3·993	20·85

Mean value of N 20·836.

Specific heat of 10 per cent. spirit 103·55.

c. Spirit 20 per cent. Sp. gravity 0·9716.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
8.	13·9	97·5	11·217	15·184	0·000	3·967	21·06
9.	13·9	97·5	11·825	15·792	0·000	3·967	20·90
10.	11·1	98·1	9·890	13·974	0·000	4·084	20·90
11.	12·9	98·2	10·486	14·535	0·000	4·049	20·97

Mean value of N 20·957.

Specific heat of 20 per cent. spirit 104·16.

TABLE II.

Copper ring, weight 614·49 grms.

Copper value of calorimeter and immersed part of thermometer 51·08 grms.

Quantity of liquid contained in calorimeter 859·3 cub. centims.

Time occupied in making each experiment, 1·5 minute.

a. Distilled Water.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
12.	12·4	97·9	10·609	16·025	0·007	5·423	15·01
13.	11·7	98·71	10·543	16·040	0·010	5·507	14·92
14.	15·4	98·15	12·656	17·945	0·015	5·304	15·03

Mean value of N 14·98.

b. Spirit 5 per cent. Sp. gravity 0·9914.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
15.	10·9	98·00	10·162	15·545	0·015	5·398	15·31
16.	12·8	98·22	10·188	15·654	0·010	5·476	15·10

Mean value of N 15·205.

Specific heat of 5 per cent. spirit 101·50.

c. Spirit 10 per cent. Sp. gravity 0·9814.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
17.	8·2	98·3	10·245	15·604	0·025	5·384	15·56
18.	11·9	97·7	9·962	15·232	0·020	5·395	15·46
19.	12·4	97·8	10·110	15·494	0·010	5·394	15·44

Mean value of N 15·503.
Specific heat of 10 per cent. spirit 103·49.

d. Spirit 20 per cent. Sp. gravity 0·9716.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
20.	12·4	98·3	11·018	16·342	0·015	5·339	15·71
21.	11·4	98·2	10·105	15·495	0·015	5·405	15·65
22.	15·4	98·6	12·589	17·877	0·010	5·298	15·59
23.	17·9	98·3	14·390	19·559	0·015	5·184	15·54

Mean value of N 15·622.
Specific heat of 20 per cent. spirit 104·27.

TABLE II. (continued).

e. Spirit 30 per cent. Sp. gravity 0·9578.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
24.	11·9	98·3	10·188	15·743	0·020	5·575	15·36
25.	13·9	98·5	10·414	15·975	0·020	5·581	15·34

Mean value of N 15·35.

Specific heat of 30 per cent. spirit 102·47.

f. Spirit 36 per cent. Sp. gravity 0·9470.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
26.	9·8	98·6	10·635	16·379	0·025	5·769	14·95
27.	11·9	98·4	10·327	16·049	0·025	5·747	15·03
28.	11·9	98·5	10·471	16·231	0·030	5·790	14·91

Mean value of N 14·966.

Specific heat of 36 per cent. spirit 99·90.

TABLE III.

Brass ring, weight 246·49 grms.

Brass value of calorimeter and immersed part of thermometer 103·55 grms.

Time occupied in each experiment $1^{m}\ 20^{s}$.

Quantity of liquid contained in calorimeter 1155·767 cub. centims.

a. Distilled Water.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
29.	20·0	98·3	19·068	20·560	0·000	1·492	51·684
30.	20·0	98·3	19·083	20·580	0·000	1·497	51·497

Mean value of N 51·590.

b. Spirit 10 per cent. Sp. gravity 0·9814.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
31.	19	98·54	18·510	19·985	0·005	1·480	53·509

Specific heat of 10 per cent. spirit 103·72.

TABLE III. (continued).

c. Spirit 20 per cent. Sp. gravity 0·9716.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
32.	19·0	98·2	17·049	18·549	0·002	1·502	54·148
33.	20·0	98·7	18·281	19·767	0·006	1·492	54·018

Mean value of N 54·083.

Specific heat of 20 per cent. spirit 104·83.

d. Spirit 30 per cent. Sp. gravity 0·9578.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
34.	19·0	98·4	17·923	19·450	0·010	1·537	53·191

Specific heat of 30 per cent. spirit 103·10.

e. Spirit 40 per cent. Sp. gravity 0·9396.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
35.	20·5	98·42	18·070	19·719	0·008	1·657	50·102
36.	17·0	98·44	16·058	17·762	0·006	1·710	49·766
37.	18·0	98·60	16·783	18·774	0·009	1·692	49·958

Mean value of N 49·942.

Specific heat of 40 per cent. spirit 96·805.

f. Spirit 45 per cent. Sp. gravity 0·9292.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
38.	19·5	98·2	18·032	19·757	0·002	1·727	48·430
39.	20·0	98·2	18·456	20·154	0·004	1·702	48·897
40.	20·0	98·4	18·244	19·970	0·000	1·726	48·456

Mean value of N 48·594.

Specific heat of 45 per cent. spirit 94·192.

g. Spirit 50 per cent. Sp. gravity 0·9184.

Experiment.	*t''*.	T.	*t*.	*t'*.	*v*.	*e*.	N.
41.	19·2	98·3	17·771	19·579	0·008	1·816	46·743
42.	19·8	98·4	18·273	20·052	0·016	1·795	47·068
43.	19·6	98·3	18·117	19·918	0·018	1·819	46·462

Mean value of N 46·758.

Specific heat of 50 per cent. spirit 90·633.

Table III. (continued).

h. Spirit 60 per cent. Sp. gravity 0·8956.

Experiment.	*t″*.	T.	*t*.	*t′*.	*v*.	*e*.	N.
44.	17·5	98·35	16·076	18·105	0·016	2·045	43·345
45.	18·5	98·48	17·535	19·538	0·006	2·009	43·405
46.	19·5	98·40	17·447	19·435	0·005	1·993	43·771

Mean value of N 43·507.

Specific heat of 60 per cent. spirit 84·332.

i. Spirit 70 per cent. Sp. gravity 0·8721.

Experiment.	*t″*.	T.	*t*.	*t′*.	*v*.	*e*.	N.
47.	16·5	98·3	17·165	19·369	0·024	2·228	40·141
48.	19·0	98·2	17·087	19·275	0·008	2·196	40·730
49.	19·0	98·4	16·881	19·088	0·010	2·217	40·539

Mean value of N 40·470.

Specific heat of 70 per cent. spirit 78·445.

j. Spirit 80 per cent. Sp. gravity 0·8483.

Experiment.	*t″*.	T.	*t*.	*t′*.	*v*.	*e*.	N.
50.	……	98·2	17·370	19·820	0·012	2·462	37·034
51.	……	98·1	17·167	19·636	0·012	2·481	36·786
52.	……	98·1	17·167	19·602	0·022	2·459	37·135

Mean value of N 36·985.

Specific heat of 80 per cent. spirit 71·690.

k. Spirit 90 per cent. Sp. gravity 0·8228.

Experiment.	*t″*.	T.	*t*.	*t′*.	*v*.	*e*.	N.
53.	……	97·60	17·293	20·000	0·020	2·727	34·074
54.	……	97·55	18·277	20·960	0·020	2·703	33·927
55.	……	98·05	15·795	18·587	0·024	2·816	33·785

Mean value of N 33·928.

Specific heat of 90 per cent. spirit 65·764.

l. Spirit 100 per cent. Sp. gravity 0·7936.

Experiment.	*t″*.	T.	*t*.	*t′*.	*v*.	*e*.	N.
56.	20·0	98·25	17·215	20·306	0·006	3·097	31·128
57.	19·0	97·60	17·674	20·708	0·012	3·046	31·266

Mean value of N 31·176.

Specific heat of 100 per cent. spirit 60·430.

At first the authors were inclined to attribute the high specific heat observed in the weaker spirits to evaporation, which, if it took place to any extent, would, of course, make the specific heat appear higher than it really is.

To test this point, they undertook some experiments in which the weight of the calorimeter with its liquid contents was carefully taken before and after the experiments, so that if any loss took place by evaporation it might become apparent. The following results were obtained.

First, with distilled water, twelve minutes intervened between the first weighing of the calorimeter before the experiment and the second weighing after the experiment.

First experiment, loss observed during the experiment . .	0·16 grm.
Second experiment, loss observed during the experiment . .	0·125 grm.

On allowing the calorimeter to stand exposed to the air for twelve minutes, a loss of 0·17 grm. in the first case, and 0·12 grm. in the second, took place, due to spontaneous evaporation. Thus the loss which could fairly be ascribed to evaporation produced by the introduction of the heated weight is quite inappreciable. Two similar experiments, made with 10 per cent. spirit, gave respectively 0·25 grm. and 0·20 grm. loss in the twelve minutes during which the experiment was made, and a loss of 0·21 and 0·21 grm. during the twelve succeeding minutes, when the calorimeter was allowed to stand exposed to the air, showing an evaporation of 0·04 grm and 0·00 grm. respectively, due to the introduction of the heated weight, a quantity which will not account for one-tenth of the effect observed.

Four experiments were then made in which the copper ring, instead of being heated to about 97° C., was heated to about 42° C.; the results are given in the following Table.

TABLE IV.

Copper ring, weight 614·49 grms.

Copper value of calorimeter and immersed part of thermometer 69·12 grms.

Quantity of liquid contained in the calorimeter 420·69 cub. centims.

Time occupied in each experiment 1·5 minute.

a. Distilled Water.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
58.	14·0	41·64	12·925	16·246	0·025	3·342	7·485
59.	14·7	41·94	12·957	16·335	0·020	3·398	7·422

Mean value of N 7·453.

b. Spirit 10 per cent. Sp. gravity 0·9814.

Experiment.	t''.	T.	t.	t'.	v.	e.	N.
60.	14·00	43·00	13·449	16·832	0·025	3·408	7·708
61.	13·25	41·81	12·339	15·693	0·020	3·374	7·771

Mean value of N 7·739.

Specific heat of 10 per cent. spirit 103·83.

It will be seen that the specific heat of the 10 per cent. spirit, deduced from these experiments, is as much above that of water as in the former experiments. To explain the results obtained in both cases as an effect of evaporation, we must make the very improbable hypothesis that the amount of liquid which evaporates during the introduction of a heated metallic body into a liquid is exactly proportional to the temperature of the body, whether it be heated to the boiling-point of the liquid or be considerably below it—an assumption obviously untenable.

Apart, however, from these experimental data, a little consideration will show that the effect observed is not due to evaporation.

The evaporation, if any, which affects the result must take place during the moment when the weight is in the act of entering the fluid; when once fairly underneath the surface, the large mass of cold liquid prevents the superheating of any part of it, whilst the effect produced by any evaporation taking place from the surface of the liquid spontaneously, is already provided for in the correction obtained by observing the fall in temperature for some time after the temperature of the calorimeter has reached its maximum.

The amount of evaporation, then, not included in this correction will depend, in the first place, on the temperature of the heated metal, which, being nearly the same in all the experiments, affects all alike; secondly, upon the time which the weight takes in actually entering the fluid, which is also alike in all the experiments, and is but a small fraction of a second; and lastly, all other circumstances being the same, this evaporation will be proportional to the surface of the heated body submerged. From the dimensions of the two weights, which have been previously given, the total surface of each, including the fan-wheel, can be calculated. It amounts to 182·4 square centimetres in the case of the copper ring, and 153·1 square centimetres in the case of the brass ring. The former weighs 614·49 grms., the latter 246·49 grms. The proportion of surface to weight is thus twice and ·1 as great in the brass weight as in the copper weight; in other words, the evaporation from the surface of the brass weight (153·1 square centimetres) will have twice and ·1 as much effect on its temperature as the evaporation from the surface of the copper weight (182·1 square centimetres) has on its temperature; yet the results obtained with the two weights are almost identical.

A series of experiments has nevertheless been undertaken, in which the specific heat of the 10 per cent. and 20 per cent. spirit was estimated, by observing the heating-effect of a known weight of either liquid, heated to a known temperature, upon a known weight of distilled water contained in a calorimeter. The liquid was at first enclosed in a thin glass bulb, which was heated with its contents to the desired point, by being immersed in a mercury-bath as recommended by Professor Kopp. The results, though generally confirming the previous experiments, did not agree among themselves as well as could be wished. This seemed chiefly owing to the fact that a globular body, having the greatest cubical capacity for a given surface, is not well adapted for the rapid cooling of its contents. In consequence of this, when about 50 cub. centims. of liquid were employed, from fifteen to twenty minutes were required to bring the temperature of the calorimeter to a maximum, or rather to the point whence the temperature began to sink; for the calorimeter frequently remained stationary at its maximum temperature for five or six minutes. On this account the correction applied amounted to a considerable fraction of the total rise observed, and great uncertainty was thereby introduced.

Having observed the beneficial effect, as regards rapidity of cooling, produced by the ring-shaped form of the weights, a hollow vessel of a similar shape was made of very thin brass, the liquid being contained in the annular space between the two sides. The external diameter of this annular vessel was about 60 millims., its internal diameter 40 millims., its height 70 millims. The annular space containing the liquid was thus about 10 millims. broad, and its capacity about 99 cub. centims.

The liquid was introduced by means of two openings at the upper part, which could be closed by small taps. The total weight of the vessel amounted to 49·66 grms.

The weight of water contained in the calorimeter, together with a weight of water equivalent, as regards the specific heat, to the vessel itself, stirrer, and immersed part of thermometer, amounted to 1165·905 grms.; and, as a mean of several concordant results, it was found that for every degree Centigrade lost by the empty annular vessel, the calorimeter and its contents gained 0°·004 C.

The annular vessel, after being filled with the liquid to be examined, was heated to the desired temperature in an oven, similar to the one used in the previous experiments, except that warm water instead of steam was used. By a simple arrangement the temperature of the water could be kept constant, whilst an effective stirrer preserved a uniform temperature in every part.

When the annular vessel, thus heated, was introduced into the calorimeter, the latter reached the maximum elevation of its temperature in five minutes, and did not remain stationary, but began to fall at once. The annular vessel was then taken out, the temperature of the calorimeter again read off at the end of three minutes, and the loss in temperature added to the highest temperature previously observed. During the whole of the experiment, the water in the calorimeter was kept thoroughly mixed by means of a stirrer. In all other respects the experiments were conducted as usual. The results are given in Table V.; they agree very well with those obtained in previous experiments; m denotes the quantity of liquid heated, in grammes.

TABLE V.

Water value of calorimeter, contents, &c. 1165·905 grms.

For each degree Centigrade lost by the annular brass vessel the temperature of the calorimeter was raised 0°·004 C.

Time occupied by each experiment 5 minutes.

a. Distilled Water.

Experiment.	*m.*	*t''.*	T.	*t.*	*t'.*	*v.*	*e.*	Specific heat.
62.	87·485	……	64·32	10·630	14·540	0·020	3·930	99·90
63.	87·485	14·9	63·70	12·646	16·389	0·020	3·763	100·06
64.	87·485	15·4	63·20	12·480	16·217	0·020	3·757	101·20
65.	91·890	14·0	62·64	10·759	14·762	0·010	4·013	101·28

Mean specific heat of distilled water 100·61. In the following experiments, however, which were made under similar conditions, the specific heat of water is assumed to be 100·00.

b. Spirit 10 per cent. Sp. gravity 0·9814.

Experiment.	*m.*	*t''.*	T.	*t.*	*t'.*	*v.*	*e.*	Specific heat.
66.	92·375	14·9	60·015	12·535	16·285	0·035	3·785	104·19
67.	92·375	13·9	59·30	12·343	16·059	0·030	3·746	104·25
68.	89·490	13·2	62·30	11·578	15·485	0·030	3·937	104·36
69.	89·490	13·7	61·80	12·252	16·076	0·030	3·854	104·60

Mean specific heat of 10 per cent. spirit 104·35, or, assuming water to be 100·00, specific heat of 10 per cent. spirit 103·71.

c. Spirit 20 per cent. Sp. gravity 0·9716.

Experiment.	*m.*	*t''.*	T.	*t.*	*t'.*	*v.*	*e.*	Specific heat.
70.	88·510	14·7	63·22	12·950	16·891	0·024	3·965	105·09
71.	88·490	15·5	61·62	13·757	17·502	0·030	3·775	105·18

Mean specific heat of 20 per cent. spirit found 105·13; or, assuming water to be 100·00, specific heat of 20 per cent. spirit will be 104·49.

After the foregoing experiments had been concluded, it was found that a somewhat similar series of experiments on the specific heat of mixtures of alcohol and water had been made by A. SCHNIDARITSCH in the year 1859, and published in Wien. Akad. Ber. vol. xxxviii. p. 39, and KOPP and WILL, Jahrb. 1859, p. 440. SCHNIDARITSCH gives the specific heat of mixtures, from 10 per cent. to 10 per cent. by volume, from water to absolute alcohol; his results, however, differ considerably from those given in this paper. From the latter it appears that the specific heat of such alcoholic mixtures, up to a strength of 36 per cent. of alcohol, is above that of water; according to SCHNIDARITSCH the specific heat of all is below that of water. In fact the specific heat obtained by him for mixtures, up to an alcoholic strength of 60 per cent., is below that obtained in the present series of experiments, whilst for all stronger mixtures and absolute alcohol his results are higher.

SCHNIDARITSCH's paper, though of some length, does not give the requisite data to check the results obtained by him, inasmuch as the correction applied in each case is not given. In his statement, however, as to how the corrections were made, there is an obvious error, as he uses REGNAULT'S formula for the amount of cooling observed in his (REGNAULT'S) calorimeter, though his (SCHNIDARITSCH'S) calorimeter is of different shape and one-fourth of the size. Any correction thus calculated which SCHNIDARITSCH has applied to his experiments will be obviously too small. Moreover SCHNIDARITSCH has experimented with but comparatively small quantities, about 10 grms. of spirit enclosed in a glass tube, whilst his calorimeter only contained 100 cub. centims.

Lastly, the thermometer employed to take the temperature of the calorimeter could only be read to $\frac{1}{50}$ of a degree, which is rather too large a fraction of the total rise observed.

His method of heating the glass tube and contents seems rather objectionable; and although the same glass tube and the *same portion* of the mixture, hermetically sealed in the glass tube, were used by him throughout the series of experiments on that mixture, yet the results obtained do not agree very well; with the 20 per cent. spirit there is a difference of nearly 3 per cent.

The authors nevertheless thought it advisable to repeat some of the experiments on the 20 per cent. spirit, estimating its specific heat between the same limits as those used by SCHNIDARITSCH. Instead of using a glass tube they employed an annular vessel (similar to the one previously described, but smaller and made of thinner brass) to enclose the spirit to be heated. This heating was effected in the same apparatus as that employed to heat the metallic weights, but the vapour of boiling alcohol was used instead of steam. In all other respects the experiments were conducted as usual.

The results of these experiments are given in Table VI.

The letters have the same signification as in previous Tables.

TABLE VI.

Amount of water in calorimeter 1155·766 grms.
Water value of calorimeter and immersed part of thermometer 9·734 grms.
Water value of annular brass vessel 2·597 grms.
Time occupied in each experiment $2^m\ 30^s$.

a. Distilled Water; amount taken 32·3475 grms.

Experiment.	t''.	T.	t.	t'.	v.	e.	Specific heat.
72.	17·30	75·5	16·502	18·220	0·008	1·721	100·55

b. Spirit 20 per cent.; amount taken 33·6255 grms.

Experiment.	t''.	T.	t.	t'.	v.	e.	Specific heat.
73.	18·0	75·60	16·723	18·549	0·008	1·834	104·55
74.	17·3	75·45	16·500	18·329	0·008	1·837	104·59

Mean specific heat 104·570.

Relying on these experiments and the considerations above mentioned, the authors have no hesitation in saying that some undetected error must have vitiated the elaborate research of SCHNIDARITSCH.

Lastly, a few experiments have been made in which the copper weight, instead of being heated, was cooled to zero Centigrade, by enclosing it in a well-fitting metal box of very thin brass, the whole being placed in a vessel filled with small fragments of ice. In about two hours the lid of the box was taken off and the copper weight rapidly transferred to the calorimeter, which had been previously filled with liquid. The lowering of temperature produced is inversely proportional to the specific heat of the liquid in the calorimeter. All evaporation which the introduction of a heated body could produce is thus entirely avoided.

Weight of copper gilt ring 614·49 grms.

Amount of liquid in calorimeter 859·3 cub. centims.

Copper value of calorimeter and thermometer 58·70 grms.

a. *Distilled water.*

In three experiments the value of N was 15·450, 15·510, and 15·901. Mean 15·62.

b. 20 *per cent. spirit.*

In three experiments the value of N was 16·549, 16·112, and 16·365. Mean 16·342.

Specific heat of 20 per cent. spirit 104·62.

The temperature of calorimeter at beginning was about 19° C.

The weight produced a depression of about 1°·15 C.

The results of these experiments do not agree among themselves as well as those obtained in previous experiments, chiefly from the temperature of the cooled weight not being ascertained, but being assumed to be zero Centigrade in each case.

The following Table (Table VII.) gives the mean result of all the foregoing experiments, the theoretical specific heat of each mixture being given as calculated from the proportions of alcohol and water present in each mixture.

TABLE VII.

Per cent. by weight of absolute alcohol.	Specific heat, found.	Specific heat, calculated.	Difference.
5	101·502		
10	103·576	96·043	+ 7·533
20	104·362	92·086	12·276
30	102·602	88·129	14·473
40	96·805	84·172	12·633
45	94·192	82·193	11·999
50	90·633	80·215	10·418
60	84·332	76·258	8·074
70	78·445	72·301	6·144
80	71·690	68·344	3·346
90	65·764	64·387	1·377
100	60·430		

Section II.—*Heat produced by the mixing of Alcohol and Water.*

The amount of heat produced by mixing alcohol and water in various proportions was estimated as follows:—

The liquid which formed the smallest portion of any given mixture was enclosed in a very thin glass bulb with a long narrow stem, the bulb and contents being carefully weighed.

The necessary quantity of the other liquid was then weighed out in a small calorimeter, made of very thin polished brass; into this calorimeter, supported as usual on stretched silk cords, surrounded by a cylinder of tin plate, and with a delicate thermometer immersed in the liquid, the glass bulb with its contents was introduced, and allowed to remain for ten minutes, the bulb itself being used to stir the liquid. At the end of that time the temperature of the calorimeter was observed; the glass bulb was then raised partly above the surface of the liquid in the calorimeter, broken by a smart tap with a file, and, by means of the portion of the broken bulb remaining attached to the stem, the contents of the calorimeter were thoroughly mixed.

In less than a minute the thermometer in the calorimeter reached a maximum, and at once began to fall; this fall was observed for thirty seconds, and added to the rise of temperature observed.

From the data thus obtained, the specific heat of the mixture formed being known, the number of units of heat evolved by 5 grms. of the mixture was calculated.

Table VIII.

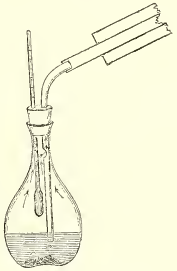
Water value of calorimeter employed 1·248 grm.
Water value of thermometer employed 0·632 grm.
Specific heat of glass of bulb 0·19.

Quantities taken of		Per cent. by weight of alcohol contained in the mixture produced.	Weight of glass bulb immersed.	Temperature of calorimeter at		Loss in thirty seconds.	Corrected rise.	Units of heat evolved by 5 grms. of the mixture.
Alcohol.	Water.			Beginning.	End.			
grms.	grms.							
79·830	8·870	90	1·7529	18·091	20·265	0·083	2·257	7·7025
73·2300	18·4075	80	1·6049	17·365	20·700	0·034	3·369	12·4775
81·1280	34·7690	70	2·6649	17·128	21·763	0·041	4·676	18·8200
62·1660	41·4440	60	3·6849	17·309	23·348	0·241	6·280	27·2620
46·1850	46·1850	50	9·3634	17·567	24·815	0·277	7·525	35·5850
37·0070	45·2308	45	7·1494	17·420	25·053	0·277	7·910	38·8095
36·6375	54·9562	40	4·0449	17·420	26·001	0·419	9·000	44·8630
29·2340	68·2125	30	2·3544	17·337	26·227	0·250	9·140	47·9800
22·8025	91·2100	20	1·5069	16·106	24·202	0·177	8·273	43·9545
11·2345	101·1105	10	1·3419	17·295	22·286	0·069	5·060	26·6850

Section III.—*Boiling-points.*

About 100 cub. centims. of the mixture whose boiling-point was to be estimated were placed in a flask of about 200 cub. centims. capacity, closed by a doubly perforated cork. In one of the perforations a thermometer was fixed in such a manner that its bulb was about ½ inch above the surface of the liquid, whilst nearly the whole thread of mercury was surrounded by the vapour of the boiling liquid.

Fig. 2.



The steady boiling of the mixture was ensured by the introduction of broken pieces of tobacco-pipes, previously ignited, into the flask.

In the second perforation a tube of moderately large diameter was inserted, which passed down to just beneath the surface of the liquid, the upper end being connected with a Liebig's condenser. In this tube a lateral opening is made, by means of a blowpipe-flame, just beneath the cork; and through the opening thus made the vapour from the flask passes into the condenser, whilst the condensed liquid runs down the tube, and is discharged just below the surface of the boiling liquid, having been raised nearly to the boiling-point in its passage down the heated tube. In this manner the composition of the liquid in the flask can be kept constant for a sufficient length of time to allow a tolerably accurate estimation of the boiling-point to be made.

It was found that the boiling-points of distilled water and absolute alcohol did not vary $\frac{1}{100}$ of a degree, whether the vapour was allowed to escape freely into the atmosphere, or was condensed and made to run back into the flask. It is, however, necessary to have the glass tube and condenser of a diameter large enough to allow the condensed liquid to run down on one side while the vapour escapes on the other. If this precaution is not taken, the condensed liquid is apt to block up the tube and prevent the free escape of the vapour; should this occur, the pressure in the flask is slightly increased, and a corresponding rise in the boiling-point at once takes place.

The thermometer employed had a range from 65° to 100° C., divided into tenths of a degree; and thus $\frac{1}{100}$ of a degree could be read off.

The following Table gives the result of the experiments, the barometer standing at 744·4 millims.

The third column gives the boiling-points calculated on the assumption that the two bodies, alcohol and water, influence the boiling-points of the several mixtures in proportion to the weights of each which those mixtures respectively contain.

Table IX.

Per cent. by weight of absolute alcohol.	Boiling-point observed.	Boiling-point calculated.	Difference.
0	99·4		
10	90·98	97·25	−6·27
20	86·50	95·10	−8·60
30	84·01	92·95	−8·94
40	82·52	90·90	−8·38
45	81·99	89·72	−7·73
50	81·33	88·60	−7·27
60	80·47	86·50	−6·03
70	79·61	84·35	−4·74
80	78·84	82·20	−3·36
90	78·01	80·05	−2·04
100	77·89		

Section IV.—*Capillary Attraction.*

A capillary tube of convenient size and length is chosen, carefully cleaned with sulphuric acid, alcohol, and water, and then thoroughly rinsed out with the mixture under examination.

The capillary tube, thus prepared, is fixed vertically in an ordinary universal screw-clamp.

A glass rod is taken, about the same length as the capillary tube; its lower extremity is drawn out and bent aside, so that it terminates in a point at some distance from the axis of the rod. A millimetre-scale is etched on the glass rod, and the vertical distance of the point from the lowest division of the millimetre-scale is carefully measured. This glass rod is fixed to the capillary tube by two india-rubber bands, the point of the glass rod being some little distance above the lower extremity of the capillary tube.

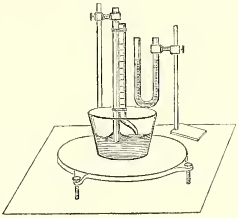
The liquid whose capillarity is to be estimated is placed in a small capsule, underneath the capillary tube. The capsule is supported on a stand, whose height can be delicately adjusted by means of three screws.

The stand is raised at first rapidly, then slowly, until the point of the glass rod just touches the surface of the liquid in the capsule. The moment when this contact between the point and the surface takes place can be observed with the greatest accuracy; and as the point is bent aside, it touches the surface beyond the influence of the capillary action of the external portion of the tube.

The height of the thread of liquid in the capillary tube is now to be read off by means of the scale etched on the glass rod. To do this with sufficient accuracy, a telescope, capable of horizontal and vertical movement, and furnished with cross wires in the eyepiece, is used.

A small U-tube, containing spirit, is fixed near the capillary tube; the eyepiece of the telescope is turned round till one of the cross wires just touches the two menisci in the U-tube; thus the cross wire is placed accurately horizontal. On slightly turning the telescope horizontally, and, if necessary, raising it vertically, the horizontal wire can be made to touch the meniscus in the capillary tube, and at the same time cut the divisions etched on the glass rod; the point where the wire thus crosses the millimetre-scale is read off, and thus the height of the thread above the surface of the liquid is determined.

Fig. 3.



This method gives very accurate results, if care be taken in the various adjustments.

The following Table gives the results obtained.

Column 1 gives the percentage of alcohol by weight.

Column 2 gives the observed height of the thread, in millims.

Column 3 gives the height supposing water stood at 100 millims.

Column 4 gives the length of a column of water equal in weight to the thread of alcoholic mixture in column 3, and affords, therefore, a measure of the relative strength of the molecular attraction in the various mixtures.

Column 5 gives the heights calculated on the assumption that they will be proportional to the weight of the constituents of each mixture.

Column 6 gives the difference between Columns 4 and 5.

Table X.

A thread of mercury in the capillary tube, 121·5 millims. long, weighed 0·4426 grm., giving 0·584 millim. as the diameter of the tube.

The temperature at which the experiments were made was 16° C.

1. Alcohol per cent.	2. Height observed.	3. Height, assuming water=100 millims.	4. Relative molecular attraction.	5. Height calculated.	6. Difference.
0	49·47	100	100	100	
10	34·22	69·17	68·07	93·11	−25·04
20	27·92	56·43	54·83	86·22	31·39
30	23·84	48·19	46·15	79·34	33·19
40	22·41	45·30	42·56	72·45	29·89
45	21·64	43·74	40·64	69·00	28·36
50	21·24	42·93	39·43	65·56	26·13
60	20·93	42·30	37·89	58·68	20·79
70	20·66	41·76	36·42	51·79	15·37
80	20·43	41·29	35·03	44·90	9·87
90	20·06	40·54	33·35	38·02	4·67
100	19·40	39·21	31·13	31·13	

Section V.—*Rate of Expansion.*

The rate of expansion is determined by carefully estimating the specific gravity of the different mixtures, at the temperatures 10°, 15°·5, and 20° C.

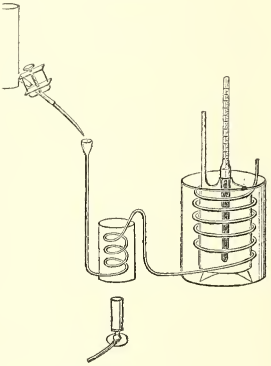
The specific-gravity bottle employed is a rather large two-necked bottle of thin glass. In one of the necks a delicate thermometer is fixed, serving as a stopper; the other neck ends in a capillary tube about 120 millims. long; 100 millims. from the upper end a mark is etched on the tube, and the capacity of the bottle, when filled up to this mark, is carefully measured. As it is difficult to fill such a bottle exactly up to the mark at a particular temperature, the level of the liquid in the capillary tube is only roughly adjusted, and the distance of the surface of the liquid from the mark accurately measured. It was found that 1 millim. of the tube contained 0·00195 cub. centim.; this being known, the quantity of liquid contained in the tube above the mark could be calculated, and its weight subtracted from that found, in order to get the weight of the contents of the flask when filled up to the mark.

The thermometer is carefully ground in to fit the neck of the flask; it has a long thin bulb passing through almost the entire depth of the specific-gravity bottle. Its range was from 8° to 25° C., divided into twentieths of a degree; and with a telescope $\frac{1}{200}$ degree Centigrade could be read off.

The specific-gravity bottle is placed in a water-bath, surrounded by a double cylinder of tin plate.

The temperature of this water-bath is under perfect control by means of the following arrangement.

Fig. 4.



The water-bath contains a coil of metal tube like an ordinary condenser. The lower end of this coil is connected with a second and smaller worm, which is contained in a small water-bath. The latter is heated by a lamp and kept gently boiling. The lower end of this second worm is bent upwards, and terminates in a long funnel. Any water poured into this funnel will pass, first through the worm, surrounded by boiling water, and be thus heated, and then through the tube in the water-bath containing the specific-gravity bottle, when it will give up its heat and raise the temperature of the water-bath. By regulating the flow of water, the temperature of this water-bath can be raised quickly, or kept constant at any desired point; so that with a little care the temperature can be raised in a few minutes from 10° to 20°, and kept within $\frac{1}{20}$ of a degree of the latter temperature for any length of time. To ensure a uniform temperature, the water is constantly agitated by the passage of a rapid current of air from below upwards.

The temperature of the bath is taken by a thermometer exactly similar to the one inside the specific-gravity bottle.

It was found that the temperature of the specific-gravity bottle could be kept within about $\frac{1}{40}$ of a degree of the temperature of the water-bath ; a more exact coincidence is not required, as the possible error thus made is quite within the unavoidable errors in filling, weighing, &c.

The bottle was weighed on a balance which turned readily with 0·0005 grm., the empty bottle being counterpoised by a second bottle of the same size and shape, to avoid any errors from hygrometric moisture.

The thermometer and barometer were observed every time a weighing was made, and the true weight *in vacuo* calculated in each case.

The mixtures were made by gradually diluting the stronger mixtures, from nearly absolute alcohol downwards; and after being made, the mixtures were exposed for twenty-four hours in the exhausted receiver of an air-pump, so that any air present might be removed.

Owing to a slight mistake in making some of the mixtures, they are not of the exact strength desired.

Weight of distilled water in specific-gravity bottle

at 10°·0 C. 545·3507 grms.,
15°·5 C. 545·0540 grms.,
20°·0 C. 544·6705 grms.

The volume of the bottle will therefore be, adopting MATTHIESSEN'S results for the expansion of water,

at 10°·0 C. 545·4985 cub. centims.,
15°·5 C. 545·5843 cub. centims.,
20°·0 C. 545·6585 cub. centims.

TABLE XI.

Per cent. of alcohol, by weight.	Specific gravity at 10° C.	Specific gravity at 15°·5 C.	Specific gravity at 20° C.
10	98396	98298	98189
20	97261	97054	96866
30	95995	95666	95392
40	94253	93854	93520
45	93262	92846	92496
50	92185	91745	91390
59·77	89994	89545	89179
69·70	87695	87219	86844
79·81	85271	84797	84410
89·89	82712	82240	81851
100·00	79792	79317	78932

TABLE XII.

Per cent. of alcohol, by weight.	Volume at 10° C.	Volume at 20° C. Found.	Volume at 20° C. Calculated.	Difference.
0	100	100·154	100·154	
10	100	100·212	100·272	−0·060
20	100	100·405	100·386	+0·019
30	100	100·632	100·489	+0·143
40	100	100·783	100·601	+0·182
45	100	100·827	100·652	+0·175
50	100	100·868	100·700	+0·168
59·77	100	100·914	100·789	+0·125
69·70	100	100·980	100·874	+0·106
79·81	100	101·020	100·954	+0·066
89·89	100	101·052	101·034	+0·018
100·00	100	101·088	101·088	

Section VI.—*Compressibility.*

The compressibility was estimated in an apparatus similar to the one employed by REGNAULT and GRASSI, but of simpler construction.

The piézomètre is a cylindrical glass tube with spherical ends, and has a long capillary tube attached at one end; it is about 150 millims. long and 32 millims. in diameter. The weight of water contained in it at 4° C. is 114·9727 grms.; and 1 millimetre of the capillary tube has a capacity of 0·000517173 cub. centim.

Air was forced into the apparatus by means of a small pump, and thus pressure was applied simultaneously to the inside and outside of the piézomètre; the amount of pressure is ascertained by the length of a column of mercury supported by it. The compression produced is read off by a millimetre-scale etched on the capillary tube.

To the compressibilities thus found, 0·000002 was always added as a correction for the compressibility of the piézomètre, this number being about the mean of the effect observed by GRASSI when a glass piézomètre was employed.

The numbers in the following Table are calculated for a pressure of one atmosphere.

TABLE XIII.

Weight of water contained in Piézomètre at 4° C. 114·9727 grms.
1 millim. of capillary gauge=0·000517173 cub. centim.

Per cent. of alcohol, by weight.	Depression, in millims.	Temperature, in degrees Centigrade.	Compression.	Calculated.	Difference.
0	40·68	9	0·00004774	0·00004774	
10	36·92	11·2	0·00004351	0·00005387	−0·00001036
20	33·00	11·5	0·00003911	0·00005998	0·00002087
30	32·92	10·2	0·00003902	0·00006584	0·00002682
40	36·88	9	0·00004347	0·00007118	0·00002771
45	39·20	8	0·00004608	0·00007364	9·00002756
50	41·60	9	0·00004878	0·00007600	0·00002722
59·77	48·20	10	0·00005620	0·00008029	0·00002409
69·70	53·25	10·1	0·00006159	0·00008426	0·00002267
79·81	59·96	9·6	0·00006942	0·00008775	0·00001833
89·89	68·76	11·1	0·00007950	0·00009140	0·00001190
100·00	81·36	9·7	0·00009349	0·00009349	

Without entering into any theoretical speculations, sufficient data for which they do not at present possess, the authors would point out certain relations, more or less intimate, which connect the various physical properties of mixtures of alcohol and water, and which have been brought out by the above series of experiments.

It will be seen by a glance at Plate LXIV. that, with one exception (*i. e.* expansion of 17 to 18 per cent. spirit), the numbers found never coincide with those calculated, as explained in the foregoing paper; in fact all the characters examined fall naturally into two classes—I. containing those which, at an alcoholic strength of 30 per cent. by weight, reach a maximum deviation from the number calculated, and II. those which reach a maximum deviation at 40 per cent. Each of these classes may be divided into two subclasses—one containing those properties in which the numbers found are above those calculated, and a second containing those in which they are below.

Class I.
a. Specific heat.
Heat produced by mixing.
b. Boiling-points.
Capillary attraction.

Class II.
c. Rate of expansion.
d. Compressibility.

On examining these in detail some remarkable facts will be noticed. In subclass *a*, Specific Heat, it will be seen, by Table VII. and Plate LXIV., that the first addition of alcohol to water, though alcohol has a specific heat much less than that of water, actually raises the specific heat; so that a mixture between 30 per cent. and 40 per cent. has the same specific heat as water.

On comparing the elevation of specific heats found, above the theoretical specific heats calculated as above, with the amount of heat produced by mixing, it will be seen (Plate LXIV.) that mixtures producing the same amount of heat possess the same elevation of specific heat; and further, if the number of units of heat produced in the formation of any mixture be divided by 3·411 in each case, a number is obtained which expresses the elevation of the specific heat of such mixture above its theoretical specific heat.

By thus calculating the specific heat from the units of heat evolved, or *vice versâ*, numbers are obtained which agree so closely with the numbers found, that the difference is quite within the limits of experimental error (*vide* Table XIV.).

TABLE XIV.

Percentage of alcohol, by weight. 1.	Theoretical specific heat (Table VII.). 2.	Units of heat divided by 3·411. 3.	Specific heat thus calculated by adding columns 2 and 3.	Specific heat found by experiment.
10	96·043	7·823	103·866	103·576
20	92·086	12·885	104·971	104·362
30	88·129	14·060	102·189	102·620
40	84·172	13·152	97·324	96·805
45	82·193	11·377	93·570	94·192
50	80·215	10·432	90·647	90·633
60	76·258	7·992	84·250	84·332
70	72·301	5·517	77·818	78·445
80	68·344	3·658	72·002	71·690
90	64·387	2·258	66·645	65·764

In subclass *b* a somewhat similar relation exists between the boiling-points and capillary attraction. Mixtures having the same depression of boiling-point have also the same depression of capillarity below that calculated; and the depression of the boiling-point may be obtained by dividing the depression of capillarity, when water rises to 100 millims., by 3·410 (Tables IX. & X. and Plate LXIV.); or the curve giving the depression observed in capillarity will be nearly the same as that giving the depression of the boiling-point, if water be taken as rising to 29·3 millims. The numbers, however, thus obtained do not agree quite so closely as do those obtained in a similar manner with the specific heat and heat produced by mixing; but it must be remembered that the boiling-point cannot be estimated with the same amount of accuracy as the specific heat, whilst it also varies with the height of the barometer, and the capillary attraction with the temperature. It might thus be possible to select a temperature and pressure in which the relation between the two properties would be as perfect as that existing between the specific heat and the heat produced by mixing.

In Class II. subclass *c* (see Table XII. Plate LXIV.), the rate of expansion, is remarkable, inasmuch as the first addition of alcohol, up to nearly 20 per cent., causes the rate of expansion to be below that calculated, whilst in all the rest of the mixtures the rate of expansion remains constantly above that calculated; and so a mixture about 17 or 18 per cent. has a rate of expansion identical with its theoretical expansion.

In subclass *d* it will be noticed (Table XIII. Plate LXIV.) that the first additions of alcohol, although the latter is much more compressible than water, produce mixtures which are less compressible than water, so that a mixture between 45 and 50 per cent. has the same compressibility as water.

Other characters, which have been examined by previous experimenters, are:—

1. *Vapour-Tension.*—This falls under Class I. subclass *b*, reaching a maximum deviation below the mean, calculated in a similar way, at 30 per cent. of alcohol, according to the researches of DRONKE, 'Ueber die Spannkraft der Dämpfe aus Flüssigkeitsgemischen. Inaugural-Dissertation, Marburg 1862; and WÜLLNER, Pogg. Ann. cxxix. 353.

2. *Specific Gravity*; and 3. *Index of Refraction.*—The two latter form a new class,

as they both reach a maximum deviation from the calculated mean at 45 per cent. These two properties have been shown to be connected with each other by DEVILLE and HOEK, Ann. de Chim. et de Phys. 3rd series, v., and Pogg. Ann. cxii.

Properties which are more nearly chemical than physical, as the solubility of various salts, have also been examined; some of these salts, as potassic chloride, reach a maximum deviation from the mean solubility at 30 per cent. alcohol; others seem to reach the maximum deviation at 40 per cent. and 45 per cent.; but the subject requires further investigation.

Thus the whole of the physical characters of mixtures of alcohol and water come to a maximum deviation from their theoretical values somewhere between 30 per cent. and 45 per cent. alcohol by weight; the 30 per cent. alcohol nearly corresponds to the formula $C_2H_6O+6OH_2$, which actually gives 29·87 per cent.; whilst 45 per cent. is nearly represented by the formula $C_2H_6O+3OH_2$, which really gives 46 per cent.

Some of the physical characters examined seem to be especially connected with each other; these are:—

1. Specific heat and heat produced by mixing; for by dividing the number of units of heat evolved by 5 grms. of any mixture by 3·411, the elevation of the specific heat of such mixture above the theoretical specific heat is obtained.
2. Boiling-point and capillary attraction, which in a similar way can be calculated from each other.

DEVILLE and HOEK have shown the specific gravity and index of refraction to be connected with each other.

Whether these relations hold good with other similar substances, whether in fact these experiments have brought forward one example of a general law, or only discovered a singular anomaly, must be left for further research to decide.

EXPLANATION OF THE PLATE.

PLATE LXIV.

UPPER HALF.

Curve 1 gives the specific heats; the vertical lines represent the percentage by weight of alcohol in this and all the following curves.

The horizontal line gives the specific heat, water=100.

Curve 2. The horizontal lines give the boiling-points in degrees Centigrade.

Curve 3. The horizontal lines give the capillarity in millims., water=100 millims.

Curve 4. The horizontal lines give the expansion for 10,000 volumes.

Curve 5. The horizontal lines give the compressibility in millionths.

LOWER HALF.

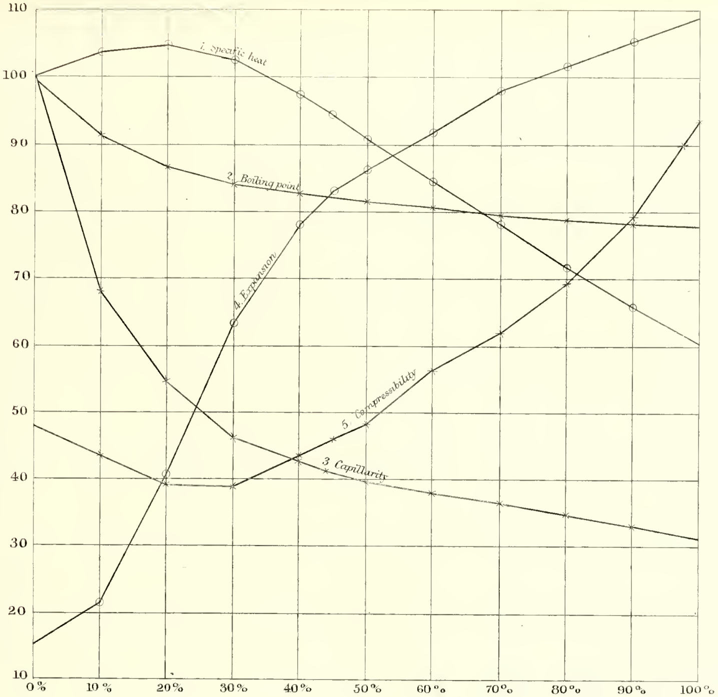
The vertical lines, as in the upper half of the Plate, give the percentage of alcohol.

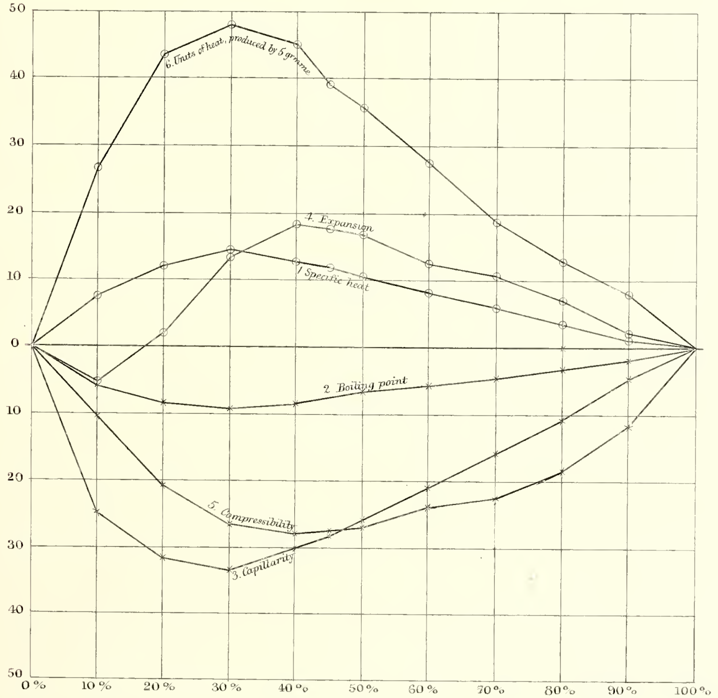
The horizontal lines in Curves 1–5 have the same significance as in the upper half, except that they give the deviations of the numbers found from the theoretical mean, instead of the numbers themselves.

Curve 6 gives the heat produced by mixing, the horizontal lines representing units of heat.

The zero line represents the mean value of all the properties.

Those belonging to subclasses *a* and *c*, specific heat, heat produced by mixing, and rate of expansion, are distinguished by a small circle round the points directly ascertained by experiment; while those belonging to subclasses *b* and *d*, boiling-point, capillary attraction, and compressibility, are similarly distinguished by a cross.





W. H. Wesley Lith.

BRITISH MUSEUM
NATURAL HISTORY.

XX. *On a certain Excretion of Carbonic Acid by Living Plants. By* J. BROUGHTON, *B.Sc., F.C.S., Chemist to the Cinchona Plantations of the Madras Government. Communicated by* J. D. HOOKER, *M.D., F.R.S.*

Received March 31,—Read April 29, 1869.

WHILE I was engaged in some experimental determinations of the changes that take place in the composition of the Cinchona barks after being taken from the tree, a somewhat singular circumstance was noticed. Some freshly gathered barks being placed in a dish over water and covered with a bell-jar, in order to prevent loss of weight by evaporation, it was noticed that after a few hours the level of the water became depressed in the jar, and that frequent bubbles of gas escaped through the water. When it is remembered that the peculiar tannin of the cinchonæ absorbs oxygen from the air, the increase in the volume of the air appeared unaccountable.

A direct experiment was therefore made, in which 5 grms. of the fresh bark of *C. officinalis* were placed with 11·2 cub. centims. of oxygen over mercury and allowed to remain for twelve hours' darkness, and seven hours' daylight. At first a considerable absorption took place, but soon gas was given off. When the mercury stood at its original level, the gas was analyzed. It consisted of 9·7 cub. centims. of carbonic acid, 1 cub. centim. of oxygen, and 0·5 cub. centim. of nitrogen.

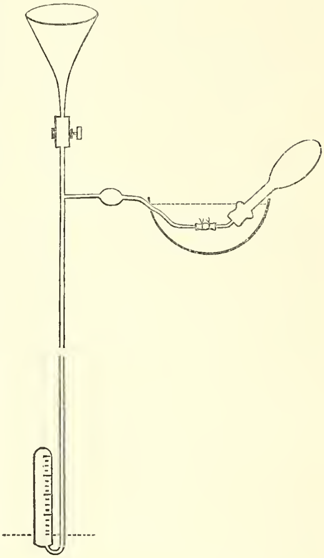
A similar trial was made in which 5 grms. of bark was kept in darkness in 11·5 cub. centims. of oxygen for the same period. The volume of the gas was but 9·6 cub. centims., of which 9·1 cub. centims. was carbonic acid, and 0·5 cub. centim. was nitrogen.

These two trials merely showed that the bark, like other vegetable tissues, absorbed oxygen and exhaled carbonic acid, and that in the second case the absorption had occurred in larger amount than the evolution of carbonic acid.

As these experiments did not account for the increase in the volume of the gas in my first observation, the trial was made of placing, as rapidly as possible, freshly cut strips of bark over mercury in a eudiometer. It was soon observed that gas was constantly given off from the bark, by the mercury descending in the eudiometer. This gas, on being analyzed, was found to be nearly pure carbonic acid. The evolution of gas continued for many days. When the bark was removed it was found perfectly fresh and healthy, and exhibited none of the reddening which is so characteristic of the Cinchona barks after having been exposed to the influence of oxygen; but as soon as it was brought into contact with the air, the greenish tint of the cut surface rapidly became brownish-red. The 5 grms. of bark had given off more than double its volume of carbonic acid, under circumstances which entirely precluded the possibility of its being produced by the direct oxidation of any constituent of the bark tissues.

The above conclusions led to an extension of the observations. As in the above case the gas was evolved under diminished pressure, experiments were tried in which the eudiometers containing the bark floated in vessels containing mercury, so that the gas was evolved under a slight increase of pressure. The gas, however, was given off in about the same proportions, and the floating eudiometers gradually rose. Other trials showed that though the slicing of the bark at first facilitated the evolution of gas, after seven days the amount was the same, whether the bark was put in whole or cut up into pieces.

Fig. 1.



In order to determine the amount and composition of the gas given off by the bark at different times, it was evidently necessary to operate upon a larger quantity than 5 grms. The plan was adopted of placing 47 grms. in a bottle connected with a Sprengel's air-pump (fig. 1); the precaution recommended by FRANKLAND* being taken—namely, that of immersing all joints in liquid, to preclude any possibility of leakage. The bottle of bark was at first carefully exhausted, and allowed to remain so for six hours, and after that lapse of time again carefully exhausted, so that the gas evolved from the bark might sweep every trace of adventitious gas that might be present. These operations were completed at dusk of evening. Subsequently the gases evolved were pumped off every twelve hours, and collected in a eudiometer over mercury, measured, and analyzed. The following Table gives the results, in cubic centimetres, corrected for temperature, pressure, and moisture.

	Gas evolved at night.			Gas evolved by day.		
	Total gas.	CO_2.	N.	Total gas.	CO_2.	N.
1st day	18·22	17·51	0·71	26·07	25·66	0·41
2nd „	21·93	21·41	0·52	19·40	18·90	0·50
3rd „	15·84	15·51	0·33	16·23	16·02	0·21
4th „	13·74	13·30	0·44	13·23	13·06	0·17
5th „	11·57	11·40	0·17	12·17	12·09	0·08
6th „	9·28	9·28	0·00	12·94	12·94	0·00
7th „	7·39	7·39	0·00	10·72	10·72	0·00
8th „	8·50	8·50	0·00	9·14	9·14	0·00
9th „	7·44	7·44	0·00	8·30	8·30	0·00
10th „	4·51	4·51	0·00	5·21	5·21	0·00
11th „	3·20	3·20	0·00	3·12	3·12	0·00
12th „	3·47	3·47	0·00	3·93	3·93	0·00
13th „	1·69	1·69	0·00	2·04	2·04	0·00
14th „	1·50	1·50	0·00	2·13	2·13	0·00

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* Journal of the Chemical Society, 2nd series, vol. vi. p. 90.

It therefore appears that during fourteen days the bark had evolved 269 cub. centims. of carbonic acid, or more than four times its own volume, under circumstances which preclude the absorption of oxygen. The Table also indicates a preponderance of the evolution during the day (a circumstance which other observations show in a marked manner). The amount exhaled during the day amounted to 143 cub. centims., that exhaled during night 126 cub. centims. The small amounts of nitrogen are probably due to some of that gas being obstinately retained in the tissues of the bark.

Other parts of various plants were submitted to the treatment described above, of exposure in eudiometers over mercury. In all cases gas was evolved. This gas did not consist, in most cases, wholly of carbonic acid, but contained nitrogen, though in far less amount. The residual gas, after the removal of the carbonic acid, was in several cases tested for oxide of carbon, and for marsh-gas; but in no instance could a trace of either be detected. The following Table contains an account of many of the experiments of this nature. The gases are reduced to the usual standards, and corrected for aqueous vapour.

Name and part of plant.	Weight, in grms.	Weight, in grms., dried.	Total gas, cub. centims.	CO_2, cub. centims.	N, cub. centims.	CO_2 from 1 grm. nat. state.	CO_2 from 1 grm. dry.	Time of experiment.
Bark of *Cupressus Lusitanica*	5·00	……	17·90	15·00	2·00	3·00	……	5 days.
Leaf of *Cinchona officinalis*, cut in pieces	0·84	0·28	0·68	0·68	……	0·80	2·40	5 „
Leaf of *Cinchona officinalis*, with petiole sealed	1·30	0·43	0·90	……	……	0·69	2·07	5 „
Leaf of *Mahonia Leschenaultii*	0·65	……	1·70	1·31	0·39	2·01	……	5 „
Wood of *Cinchona officinalis*	5·00	2·75	1·20	0·70	0·50	0·14	0·25	5 „
Twig with leaves of *Cinchona officinalis*, stalk sealed	4·75	1·50	6·90	6·62	0·28	1·39	4·41	4 „
Leaves of dwarf bamboo	10·00	3·25	5·55	4·83	0·72	0·48	1·48	5 „
Blades of *Festuca ovina*	10·00	2·68	21·97	19·51	2·46	1·95	7·28	5 „
Rhizome of *Iris Germanica*	4·75	1·13	11·70	11·10	0·60	2·33	9·82	5 „
Spadix of *Richardia*	3·00	0·50	9·35	8·75	0·60	2·91	17·50	5 „
Pseudo-bulb of an orchis	5·25	1·25	1·60	1·50	0·10	0·28	1·20	5 „
Rootlets of *Acacia dealbata*	10·00	2·00	5·70	5·00	0·70	0·50	2·50	5 „
Rootlets of *Festuca ovina*	10·00	2·75	25·80	24·60	1·20	2·46	8·94	5 „
Woody stems of *Erica pubescens*	5·00	2·50	11·90	11·30	0·60	2·26	4·50	5 „
Leaves of *Erica pubescens*	5·00	1·25	7·90	5·80	2·10	1·16	4 64	5 „
Leaves of *Cupressus Lusitanica*	10·00	4·75	13·50	12·60	0·90	1·26	2·65	5 „
Phyllodes of *Eucalyptus globulus*	5·00	2·50	10·50	8·90	1·60	1·78	3·56	5 „

Among a larger number of experiments, conducted with various portions of phanerogamous plants, I have not found a case in which carbonic acid failed to be given off, in greater or less amount, when they were exposed in a tube over mercury. Even mosses and liverworts show the same reaction, though in many instances the quantity exhaled is but small. A plant of *Jungermannia*, however, gave off absolutely no gas for three days; but at the end of that time a small quantity appeared. This was found to be carbonic acid. The probable reason why these lower orders of plants, rich as they are in chlorophyll, and in active growth, evolve in many cases a less amount of gas, is indicated in the general conclusions of this memoir.

The actual amount of gas evolved from different plants or different parts of the same plant varies very considerably. Generally speaking, it seems to be greater according to the activity of the plant's growth. It is also given off at a greater rate when the temperature is increased. Daylight also has a stimulating effect, which is sometimes very marked, and is irrespective of temperature*.

The phenomenon is entirely dependent on the life of the tissues. Causes which arrest life also arrest the exhalation of carbonic acid. Immersion in water at 60° C. for two minutes entirely deprives the part of the property, whether it be bark, leaves, flower, or roots. Sudden drying *in vacuo* over sulphuric acid has the same effect, even when the plant is allowed to imbibe water till it has the appearance of life. In both cases it will remain for days without gas appearing in the eudiometer. Even living parts of plants in a state of rest give off no gas. Such is the case with the tuber of a potato.

It will be observed in the foregoing tabular statement that in most cases nitrogen gas is also given off. In the greater part of these it is due to the tissues of the plant containing air. This was experimentally proved in the case of the phyllodes of *Eucalyptus globulus*. It will be seen in the Table that 5 grms. of these gave off 1·60 cub. centim. of nitrogen. But when the phyllodes were put into a vessel connected with the mercurial pump in the manner before described, and thoroughly exhausted, the gas subsequently exhaled was pure carbonic acid. In some other cases it was found impossible to introduce leaves &c. into the eudiometers without some adherent air, and hence the source of nitrogen. But from Fescue grass nitrogen was actually evolved in considerable quantities. It was remarked that the grass altered its colour in the eudiometer, and, unlike most plants, suffered by the treatment to which it was subjected. To ascertain more fully the conditions of this exhalation of nitrogen, two similar bottles were filled with blades of the grass. One was placed in connexion with the Sprengel pump, the other served for occasional examination. The following numbers were obtained from 85 grms. of grass.

Gas of day.			Gas of night.			
Total gas.	CO_2.	N.	Total gas.	CO_2.	N.	
54·5	54·5	0·00	30·9	30·9	0·00	No decomposition apparent.
28·2	26·79	1·41	24·2	20·32	3·88	
36·5	31·50	5·00	32·8	27·67	5·13	
34·0	26·73	7·27	46·5	38·73	7·77	Faint smell of decay.
38·5	29·92	8·58	44·2	35·91	8·29	Fermentation set in.

Hence from grass it will be observed that the evolution of nitrogen continually increased in amount, and was coincident with the setting in of decomposition. I am I think justified in attributing the production of nitrogen to the breaking up of the nitrogenous constituents of the plant. The grasses are exceptionally unsuitable subjects for this kind of investigation, from the readiness with which they begin to ferment when in mass. Many kinds of leaves with which I have experimented appeared quite fresh and unchanged after fifteen days' confinement in the eudiometer.

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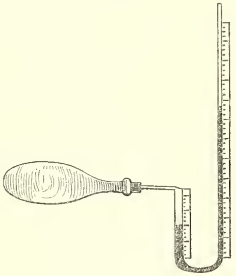
* Leaves immersed in carbonic acid have been shown by BOUSSINGAULT (Compt. Rend. vol. lx. p. 872) to have no power of decomposing the gas under the influence of light.

When the investigation had arrived at this stage, it became necessary to consider the somewhat exceptional conditions under which the experiments were made. The plants grew and were experimented with on the Neilgherries at a height of 7400 feet, or 1·4 mile up in the air. Hence the gases would meet with less mechanical impediments to their evolution than at the sea-level. To ascertain whether this circumstance had any essential effect on the phenomena, soda-water bottles were filled with leaves of *Erica*, fresh Cinchona bark, &c., and connected with manometer-tubes containing mercury (fig. 2). Soon the mercury began to rise, being pressed upwards by the gas exhaled, until the total pressure had become equal to 30 inches. Then it continued to rise several inches higher. In one case a final pressure exceeding a whole additional atmosphere was reached. The leaves were perfectly healthy, and showed no trace of any decomposition. In addition to these experiments others were made, in which the bottles filled with leaves &c. were fitted with delivery-tubes, whose ends were plunged a few inches below the surface of mercury. The gas was collected in a eudiometer. The results confirmed the other observations. This form of the experiment is well suited for a lecture illustration. Hence it is concluded that variations of atmospheric pressure within wide limits do not essentially affect this peculiar evolution of carbonic acid.

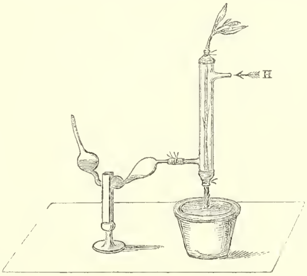
Fig. 2.



All the foregoing experiments were performed with portions of plants separated from the root, and therefore under somewhat abnormal conditions. The important question arises, whether the same phenomenon constantly occurs in plants growing under ordinary conditions. Although there could be *à priori* little doubt of this, an experimental proof was desirable. It is one that offers many practical difficulties, and I have endeavoured to effect it as follows.

I was first anxious to detect the exhalation of carbonic acid from growing Cinchona bark. As a preliminary qualitative experiment, I took a healthy young plant of *C. officinalis*, about two years old; and by plucking off all the leaves from the stem, except those of the terminal shoot, it was enabled to be passed into a tube of glass, resembling the outer tube of a Liebig's condenser (fig. 3), which was then made air-tight at each end by means of sheet caoutchouc and cement. The intervening space, between the enclosed bark and the wall of the tube, was filled with hydrogen and allowed to remain for a day. It was then cleared out by a stream of hydrogen, and the upper branch tube conveying the hydrogen tied. The lower one had

Fig. 3.



been arranged to deliver any gas that might be evolved into a eudiometer over mercury. But the gas was delivered in a very unsatisfactory manner, owing to the pressure that had to be overcome before the gas could pass into the eudiometer. At the end of two days, however, a few bubbles had passed, which, when tested by a potash pellet, showed the presence of carbonic acid by a marked absorption.

The plan was then adopted of passing a slow stream of hydrogen (well purified by passing through tubes of pumice moistened with a strong solution of argentic nitrate and through a pair of potash bulbs) through the intervening space and then through a nitrogen bulb containing baryta-water. In this way the constant evolution of carbonic acid by the bark was readily detected by the precipitation of baric carbonate. The experiment was continued for nine days. The last three days the amount was estimated: the vols. of carbonic acid, corrected to the ordinary standard of pressure, were as follows:

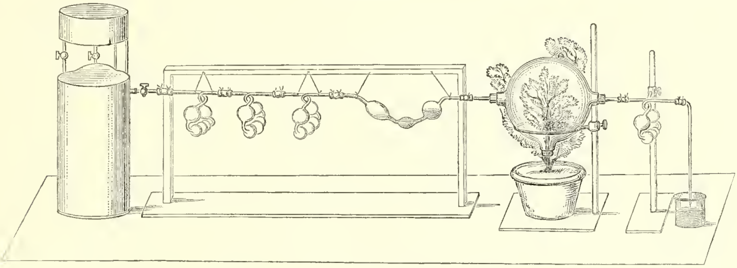
7th day	2·10 cub. centims.
8th ,, ...	1·54 cub. centim.
9th ,, ...	1·64 cub. centim.

Immediately after the conclusion of the experiment, the bark, which had for so long been in contact with hydrogen only, was quickly cut off the plant, and as rapidly as possible passed into a eudiometer over mercury. Carbonic acid soon made its appearance, and after three days its amount was estimated. Its corrected volume was 6·21 cub. centims. The surface of the bark included in the tube exposed a surface of 18 square inches.

In applying the same method for the purpose of ascertaining the evolution of carbonic acid from leaves while growing on the plant, very considerable difficulty was experienced in continuing the experiment long after the exclusion of oxygen. This was owing to the plant suffering from the effects of the hydrogen employed. This gas, when generated in the usual manner from zinc and sulphuric acid, even after the most careful purification I could devise, had such a poisonous effect on the fresh leaves, that after three days' exposure they became yellow and died. I am inclined to attribute this to some impurity in the gas (as a trace of arsenic) which was not perfectly removed by the means of purification adopted. I tried several plans of purification and several kinds of plants. In all cases I found carbonic acid evolved; but I was never able to continue the experiment a sufficient length of time without the leaves becoming manifestly unhealthy, and thus introducing a source of doubt. After many trials I found that carefully washed and purified nitrogen was the gas best suited for my purpose. I found also that a branch from a plant of *Erica pubescens* appeared perfectly healthy and fresh after many days' exposure to the gas.

I therefore finally adopted the following arrangement, which will be readily understood by the annexed sketch (fig. 4). Nitrogen gas contained in the gas-holder was slowly passed through two Liebig's potash bulbs containing a solution of pyrogallic acid in strong potash, then through a similar bulb containing a solution of potash, after this through baryta-water in a Will's nitrogen bulb (which remained clear to the end). The pure gas then passed into the three-necked globe containing the branch of *Erica*, the latter being secured in one neck by means of a perforated stopper of soft caoutchouc with a side slit for the introduction of the stem, so that, being firmly thrust into the neck, it made an air-tight joint. The issuing gas then slowly bubbled through a potash bulb, which was periodically weighed—or else, when a test was required, through baryta-water. Contamination with the external air was prevented by finally allowing the gas to go into distilled water.

Fig. 4.



The gas was passed before regular determinations were made. During this period occasional tests were made with baryta-water, which always showed the presence of carbonic acid. On the seventh day the gas was passed through the potash bulbs, which were weighed night and morning. The following were the results:—

	By day, weight in grammes.	By night, weight in grammes.
7th day	0·0186	0·0202
8th „	0·0362	0·0532
9th „	0·0375	0·0335
10th „	0·0395	0·0133
11th „	0·0372	0·0152
12th „	0·0183	0·0125
13th „	0·0566	0·0147
14th „	0·0089	0·0194
16th „	0·0464	0·0194
17th „	0·0186	0·0016
18th „	0·0210	0·0121

The foregoing numbers indicate that the branch of *Erica* evolved carbonic acid long after being excluded from the influence of oxygen. The mean amount during the last eleven days was somewhat over 1 cub. centim. per hour. In this experiment the exhaled carbonic acid, being mingled with a large amount of inert nitrogen, was liable to be decomposed by the plant during day. This circumstance was doubtless a source of loss of carbonic acid, but it was unavoidable.

The excretion of carbonic acid by plants has generally been ascribed to a process analogous to the breathing of animals, oxygen being absorbed and carbonic acid exhaled. The greater part of the carbonic acid exhaled has doubtless this origin, but it is clear from the foregoing experiments that it will not account for the whole. They show that plants, when placed in circumstances where access of oxygen is no longer possible, continue to give off carbonic acid, in quantities and under conditions which involve the conclusion that it is a necessary function of the life or growth of the plant.

There appear to be but two ways of accounting for this excretion of carbonic acid:—1st. It may possibly be due to absorption of oxygen occurring long prior to the exhalation. 2nd. It may be due to the direct giving off of carbonic acid in consequence of the chemical changes occurring in the plant. It may also be a consequence of both conjointly.

If it were possible to exclude oxygen from a plant during the whole of its life, or if a plant could be grown for some months in a mixture of neutral gas and carbonic acid, the exhalation of the latter gas must necessarily be ascribed to the second hypothesis. Experiments in this direction, however, offer extreme difficulties, or are even impossible. De Saussure states that no plants will live in an atmosphere destitute of oxygen. There is, however, a doubt whether this conclusion is perfectly general.

There is, however, another plan by which considerable light may be obtained in the matter. It consists in ascertaining the quantitative effect produced on the exhalation of carbonic acid from parts of plants by their exposure to the oxygen of the air during periods of known direction. This I have endeavoured to carry out as follows.

A certain weight (usually 5 grms.) of leaves or bark was exposed to air for twenty-four hours in a bell-jar over water immediately after being separated from the plant. In the case of bark it was found necessary to do this while still attached to the wood. An equal amount, as similar in character as possible, was exposed for the same period to an atmosphere of nitrogen. Thus the two cases only differed by a day's exposure to the influence of oxygen. The effect of this was ascertained by placing each in a eudiometer over mercury, and measuring the respective amounts of carbonic acid given off each day.

The following Tables express the results obtained. The first column gives the number of days after the separation from the plant. Column marked "Air" relates to the specimen exposed to air, that marked N refers to the one placed in nitrogen. The column Δ expresses the difference of the two, or the effect of a day's exposure. The results are given in cub. centims. of dry CO_2 reduced to the ordinary standard.

Bark of *Litsæa oblonga.*				Bark of *Cupressus Lusitanica.*				Bark of *Acacia dealbata.*			
I.	Air.	N.	Δ.	I.	Air.	N.	Δ.	I.	Air.	N.	Δ.
2	6·20	5·50	0·70	2	2·06	1·53	0·53	2	5·14	4·09	1·05
3	6·13	4·37	1·86	3	2·54	2·05	0·49	3	3·85	3·04	0·81
4	5·06	4·10	0·96	4	2·20	1·91	0·29	4	4·37	4·30	0·07
5	4·39	3·76	0·63	5	2·10	1·94	0·16	5	2·61	2·60	0·01
6	4·26	3·70	0·56	6	1·65	1·65	0·00	6	2·10	2·10	0·00
7	3·39	3·35	0·04	7	1·49	1·49	0·00	7	1·61	1·61	0·00
8	2·89	2·89	0·00	8	1·20	1·20	0·00				
9	2·38	2·38	0·00	9	1·05	1·05	0·00				
10	1·62	1·64	−0·02								
11	1·74	1·74	0·00								
12	1·72	1·72	0·00								
13	0·85	0·85	0·00								

The subjoined Table gives the results of a similar experiment with the leaves of *Buxus sempervirens*, which were found particularly suitable for the purpose from their activity and the hardiness with which they stand the hardships of their treatment without the least apparent injury.

Leaves of *Buxus sempervirens.*

I.	Air.	N.	Δ.
2	7·11	5·97	1·14
3	4·74	3·98	0·76
4	4·38	2·74	1·64
5	2·79	2·40	0·39
6	1·86	1·61	0·25
7	2·32	2·07	0·25
8	1·53	1·29	0·24
9	1·22	1·13	0·09
10	1·09	1·09	0·00
11	0·95	0·95	0·00
12	0·87	0·87	0·00

Similar but less-extended results were obtained with the leaves of *Veronica salicifolia*, which appeared to suffer from their treatment. I do not, therefore, quote them.

The above Tables demonstrate the fact that exposure to air for one day markedly increases the amount of carbonic acid during many subsequent days. Hence the hypothesis (1) enunciated above expresses (partly at least) the true origin of the carbonic acid given off by plants when confined over mercury. It is really due in a great measure to prior oxidation. Some other general conclusions may be fairly educed from this result.

It is of course well known that plants by exposure to air constantly absorb oxygen and exhale carbonic acid. Now the further fact may be added, that, of the oxygen absorbed during a day, part may not appear as carbonic acid till after the expiration of a week. This explains the circumstance noticed by De Saussure and others, that the volume of carbonic acid exhaled during a day is sometimes more and sometimes less than that of the oxygen absorbed. The actual process is not so simple as has been generally supposed. Thus, when a plant is observed during a certain day to absorb oxygen and give out carbonic acid, the greater part of the latter is due to the oxygen absorbed during that day; but some is derived from that absorbed the day previous, a smaller amount from the oxygen of the day previous to that, and so on back for several days. On the other hand, the oxygen absorbed is excreted as carbonic acid for the greater part on the same day, but by no means the whole; for decreasing amounts will be the source of part of the carbonic acid exhaled by the plant during the ensuing week.

But it is to be observed that the whole of the carbonic acid exhaled by the barks and leaves in the above experiments cannot be referred to previous oxidation. This is clearly shown by the foregoing tabular statements. Thus, in the case of the bark of *Litsæa oblonga*, it is seen that the differences gradually diminish in value and finally disappear, while a considerable amount of gas is still daily exhaled. This gas cannot be attributed to any previous oxidation, since the very latest exposure to oxygen has ceased to be perceptible. The total daily amount of excreted carbonic acid is hence not comminuent with that which is the effect of the single day's exposure, as would be the case if the carbonic acid had no source but that of previous oxidation. It therefore is evident that some of the carbonic acid has another source.

Again, if the peculiar exhalation of carbonic acid, which I have in the foregoing pages endeavoured to investigate, were exclusively due to previous oxidation, it is obvious that the amount in column "Air" for any day should not exceed the sum of the numbers in column "Δ" for that and all subsequent days; but it does exceed this sum in all cases. This consideration corroborates the conclusion that there is another source of carbonic acid.

There is an objection to this reasoning which can be made with some justice. "How can we be certain," it may be urged, "that the result of a single day's exposure to an oxidizing atmosphere is proportionally the same as that of several consecutive days, or as in nature, where the exposure is of course continual? Perhaps in this case a *greater* proportional effect may take place, and thus the whole amount of carbonic acid may be accounted for."

This doubt, however, admits of an experimental resolution. If it be true that longer exposure causes proportionally larger amounts of carbonic acid to be subsequently evolved, then, in a differential experiment like the foregoing, if the time of exposure to air be doubled, will the sum of the differences approach *nearer* to the actual amount exhaled on any particular day?

To determine this point, an experiment resembling the preceding was made, with the difference that the box-leaves were respectively exposed to air and nitrogen for forty-eight hours instead of twenty-four. The results of the subsequent determinations were as follows:—

Leaves of Box.			
I.	Air.	N.	Δ.
3	6·40	4·95	1·45
4	6·96	5·05	1·91
5	4·88	4·55	0·33
6	3·26	2·88	0·38
7	2·65	2·33	0·32
8	1·52	1·15	0·37
9	1·45	1·15	0·30
10	0·86	0·84	0·02
11	0·76	0·76	0·00
12	0·45	0·45	0·00
13	0·45	0·45	0·00

An examination of the foregoing Table shows that the sum of the nth, $n+1$th, $n+2$th, &c. differences approaches *less near* the nth term in column "Air" than in the former experiment, where the exposure was but for twenty-four hours. This, however, is only true in the mean. Calculating from the first seven terms of both Tables, the sum of differences differs from the nth term in the "Air" column by a mean of 1·49 and 1·89 respectively.

It must therefore be concluded that part of the carbonic acid exhaled from vegetable tissues arises from a source independent of oxidation. It must therefore be due to a separation of the gas from one or several of the proximate constituents of their tissues in consequence of the chemical changes therein taking place.

This is a view that is by no means novel. ROCHLEDER* and others have already advanced it as an hypothesis. Indeed the former appears inclined to attribute the evolution of carbonic acid to this cause, even in some cases where it is ordinarily regarded as a direct product of the so-called plant respiration. Moreover there are several facts in the known chemistry of plant-growth which harmonize with this view. It is easily seen that the subtraction of the elements of carbonic acid from any vegetable principle will have the result of leaving a residue richer in both carbon and hydrogen, and hence of higher force-value.

There are grounds for believing that woody tissue is derived from the starch secreted under the influence of sunlight in the leaves of the plant. But as these tissues contain a larger percentage of carbon, and have a higher force-value than starch, this change would be effected by the separation of a substance having a less force-value, as is the case with carbonic acid, in which the energy of combination is nearly exhausted. (A decomposition of this nature occurs in the slow changes by which wood is converted into lignite and coal.) The conversion of starch into fats in plants is a change which there are experimental grounds for believing to be one of constant occurrence. It has been observed that during the ripening of oily seeds the starch disappears as the oil is formed. This change can scarcely be explained without assuming the subtraction of carbonic acid as in the decomposition by which alcohol, glycerine, and fatty acids are derived from sugar in vinous fermentation. The direct conversion of sugar into wax, with the evolution of carbonic acid, is known to occur by the agency of bees.

SACHS has shown that some seeds which contain no tannin develope that substance during the first growth after germination, with a simultaneous disappearance of starch. The period at which it occurs would preclude the direct formation of tannin from external sources. The tannins contain a less percentage of oxygen than the class of carbohydrates; and their derivation from the latter, attended by the separation of carbonic acid, is an hypothesis supported by the facts of the case. Without assuming unusual or improbable decompositions, it is scarcely possible to explain such conversions, unless this separation be assumed.

The state in which the oxygen absorbed by the plant remains, until it is finally excreted in combination with carbon, is a point of great interest. In order to ascertain whether it might not possibly be *occluded* by the tissues, an experiment was performed. A considerable quantity of willow bark was placed in a flask connected with a Sprengel pump, and so arranged that it could be exhausted while heated in an oil-bath. At temperatures varying from 17° to 60° C. considerable quantities of carbonic acid gas were evolved, showing that the rise of temperature markedly increased the excretion of this gas. But as soon as the temperature rose above the coagulating-point of albumen, gas quite ceased to be evolved, although the pump was kept at work and the temperature raised to 160° C. The experiment hence gave no support to the idea that the oxygen was occluded. The constituent in plants which acts in relation to oxygen as the blood-corpuscles in animals is quite unknown.

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* Chem. u. Phys. d. Pflanzen, 1858, p. 113 und 151.

It is a rather remarkable fact that growing cinchona bark, which contains a large amount of a tannin greedy of oxygen, continually absorbs oxygen, retains it for days, and excretes carbonic acid, without in the least affecting the easily alterable tannin.

The main conclusions which are arrived at by the foregoing investigation are:—

1st. That nearly all parts of growing plants evolve carbonic acid in considerable quantities, quite independently of direct oxidation.

2nd. That this evolution is connected with the life of the plant.

3rd. That it is due to two causes—namely, to previous oxidation, resulting after a lapse of time in the production of carbonic acid, and to the separation of carbonic acid from the proximate principles of the plant while undergoing the chemical changes incident to plant-growth.

XXI. *Researches on Turacin, an Animal Pigment containing Copper.* *By* A. H. Church, *M.A. Oxon., Professor of Chemistry in the Royal Agricultural College, Cirencester. Communicated by Dr.* W. A. Miller, *Treas. and V.P.R.S.*

Received May 4,—Read May 27, 1869.

Origin of the present Inquiry.—The stability of the colours which the feathers of birds display has been repeatedly proved. These colours are due either to what we may call the optical character of the surfaces of the web, or to the presence in it of definite colouring-matters. These pigments may be opaque like enamel, or translucent and permeating the substance of the barbs; they have been as yet but very imperfectly studied. In a few instances only have they been actually separated from the structures containing them, while in no case have they been completely examined from a chemical point of view. So far as I can learn, we have no exact information as to the amount and the deportment, chemical constitution and reactions of those substances which M. Bogdanow*, some twelve years ago, succeeded in extracting from the feathers of many birds, and notably from the red feathers of *Calurus auriceps* and *Catinga cœrulea.* Before giving an outline of my own experiments in this direction, I will mention the particular circumstances which led to the prosecution of the present research.

A few years ago Mr. W. B. Tegetmeier pointed out to me a singular property of the red feathers of the bird called the Touracou, or Plantain-eater. These feathers yield up a part of their colouring-matter to pure water, a beautiful rose-coloured solution being thus obtained. Mr. Tegetmeier's attention had been drawn to this fact, and he at once perceived that it was worthy of fuller investigation than it had already received. On further inquiry, I find that Mr. Ward of Wigmore Street had noticed the evanescence and solubility of the red tint in question many years ago, and that other observers, within the last few years, have even succeeded in staining pieces of paper with the red solution which these feathers yield. In order that it may be seen what was the position of the inquiry when I commenced in 1866 my experiments on this subject, I may cite the authority of some private letters which have been placed at my disposal through the courtesy of Mr. Hugh Owen. These letters were written by Dr. Benjamin Hinde, principal Medical Officer on the Military Staff at Bathurst, on the Gambia. In one of his letters, dated May 1865, Dr. Hinde enclosed a piece of paper stained with the red pigment of 1 inch of a feather of the violet Plantain-eater, *Musophaga violacea.* He says that the moment soap touches the feathers the colour runs, but that it is difficult of extraction with pure water. But he adds, " the birds I sent home washed themselves nearly white in the water left for them to drink!" In a subsequent letter Dr. HINDE gives some details concerning the different species of Plantain-eaters, and says, with reference to the feathers he had previously sent to England, "all the feathers sent were from the same bird and grew in this house." This fact negatives any idea of an artificial dye being present in the feathers, and is further referred to in the following memoranda by Mr. HUGH OWEN:—"A pair of violet Plantain-eaters from the Gambia were sent over to a friend in Ireland by Dr. HINDE. The birds arrived in excellent condition, and were speedily provided with ample space and all appliances for cleanliness. For a while this splendid plumage, the deep crimson patch on the dark violet of the wing, excited continual admiration. After a day or two the crimson faded; in a few more the colour changed to a pale and dirty grey. The disappointed owner wrote an account of this change to Bathurst, concluding, of course, that the natives had imposed on Dr. HINDE by selling him a pair of painted birds: this, however, was impossible; there was no mistaking the peculiar and shield-shaped bill or the legs of the Musophaga. Whatever change had taken place, the birds were genuine Touracous. Without delay another bird was procured, so young as to be only partly fledged, the wings only in the pin-feathers. As soon as these were sufficiently grown, the experiment was repeated, and the colour found to be inconstant and capable of extraction." The data already given, and many others with which I have been subsequently furnished, incontestably prove the normal presence, in some of the feathers of the Plantain-eater, of a red pigment soluble in water, and still more readily dissolved by soap. I may now give my own results as to the preparation and physical and chemical properties of this new red animal pigment.

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* Comp. Rend. xlv. p. 688; xlvi. p. 780.

Occurrence of Turacin.—The birds from which I have extracted this colouring-matter generally go under the designation of Plantain-eaters, from their favourite food. It would appear that the native name for them is represented by the word Touraco; while the Dutch speak of one of the species as the Cape Lowry. These birds are entirely African. They belong to the Order Scansores and the Family Musophagidæ; they are closely related to the Cuculidæ or Cuckoos. There are three genera of Touracos—*Musophaga*, *Corythaix*, and *Schizorhis*—altogether including eighteen species. The red pigment occurs in twelve only of these birds, namely, in both the known species of *Musophaga* and in ten out of the eleven species of *Corythaix*. The eleventh species of *Corythaix*, in which it does not occur, is the Giant Touracou, which diverges in many other particulars from its brethren. The following is a list of the species from which I have actually obtained the pigment; in the others, named above, I have merely recognized its presence by optical means:—

Musophaga violacea.
Corythaix (Turacus) porphyreolopha.
—— *erythrolopha.*
—— *albocristata.*

The plumage of these birds does not present any great general brilliancy. The red pigment occurs in the primary and secondary pinion-feathers, from twelve to fifteen of which have either a crimson blotch upon them, or are almost wholly coloured. I propose the name Turacin for the red pigment which the Touracou (*Turacus*) contains. In order to extract this pigment the plan finally adopted was as follows:—

Isolation of Turacin.—The barbs constituting the red part of the web are stripped from the shaft of the feathers, placed in a beaker, and washed with ether and then with alcohol. This treatment removes the grease and adhering dirt very effectually. When the red barbs thus washed have been dried between folds of filter-paper, they are placed in a cold very dilute solution of pure caustic soda, a solution containing one part of soda in a thousand of distilled water being quite strong enough. Ammonia, potash, or the carbonated alkalies may be used in lieu of caustic soda. The mass is stirred at intervals for fifteen minutes, or thereabouts; the crimson solution is poured off and pure water added; by successive treatment of the barbs with fresh portions of dilute alkali and pure water, the whole of the crimson pigment is obtained in solution, the residual barbs becoming white or pinky grey. All the coloured liquors having been filtered and mixed, they are poured in a slender stream, with constant stirring, into dilute hydrochloric acid, made by mixing one part of the pure commercial acid with four parts of water. When the red precipitate of the pigment thus coagulated and rendered insoluble has settled, the supernatant liquid is decanted off and the red matter thrown upon a wetted filter and washed with water. (A still better plan is to employ a decanting siphon filter for the separation and washing of the precipitate.) The liquid comes through quite colourless, until there is no longer a trace of acid left in the pigment on the filter. When this occurs, the residue is washed with water containing a few drops of acetic acid to the pint, and then syringed out of the filter into an evaporating-basin and dried at a gentle heat. The dry pigment is next to be washed with a mixture of alcohol and ether, and once more dried. It is now perfectly pure and yet unchanged, so far as I have examined it.

Properties of Turacin.—Prepared as above described, turacin occurs in scales which have a deep violet-purple colour by reflected light, and showing a crimson tint when seen in small fragments by transmitted light. Its powder is of a dull crimson tint. It has not been obtained in a crystalline form. It is very slightly soluble in pure water, giving a pale rose-pink solution. The presence of acids and salts renders water incapable of dissolving it. It is not soluble in pure alcohol or ether. In alkaline liquids it immediately dissolves, forming solutions which show a bluer tint than the original pigment. In fact turacin is a very delicate test for the alkalies. For example, perfectly pure barium hydrate in solution does not dissolve turacin; but let a minute trace of soda exist, as it often does, in the baryta-solution, and then the liquid will become readily tinted if shaken up with a fragment of turacin. Very strong solutions of the caustic alkalies dissolve the pigment, but at the same time it suffers a partial decomposition, evidenced by an odour resembling that of certain bases of the pyridine series, which it then evolves. Fuming nitric acid dissolves it with a deep brown tint, destroying it; in oil of vitriol it is soluble, but in all probability with partial alteration. Turacin seems to have slightly acid properties; though it dissolves very freely in carbonated alkalies, caustic alkalies are still more effective. Turacin by long exposure to air and moisture, or by continued ebullition with water or alkaline liquids, acquires a colour closely resembling that of chlorophyll.

Spectrum of Turacin.—If a piece of the red web of a Touracou's feather be examined with a prism, two black bands will be at once perceived about the lines D and E of the solar spectrum (fig. 1). These bands correspond to some extent with those of STOKES's red cruorin, but it will be seen (fig. 2) that they are not identical. When an alkaline solution of turacin is similarly examined, the bands (fig. 3) are shifted further from D, while the blue region of the spectrum is less shaded than it is with the original red of the feather, or with coagulated turacin precipitated by an acid. When the alkaline solution of turacin is dilute, the band near E is very weak; but when a strong solution is employed, both bands became equally intense, and finally almost coalesce, nearly obliterating the space in the green between them. No results have attended my attempts to produce in turacin, by ferrous or stannous salts, a reduction similar to that obtained in red cruorin by the same means. Coagulated turacin in water, and more particularly the web of the red feathers, present by transmitted light very nearly the appearance of diluted arterial blood to the eye.

Fig. 1.

Spectrum of Turacin as it exists in the feathers.

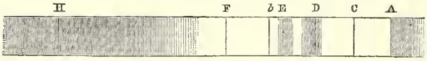
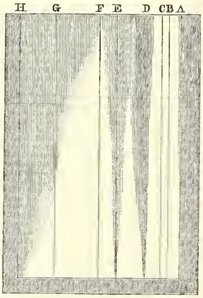


Fig. 2.

Spectrum of Cruorin.



Spectrum of Turacin

in soda.

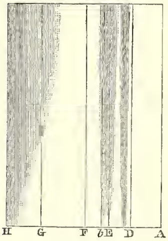


Fig. 3.

in soda after long boiling.

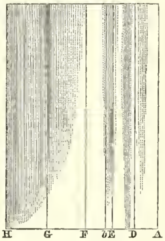


Fig. 4.

The change in the colour of turacin produced by exposure to air and moisture may be traced in the spectrum of the altered substance (fig. 4). The specimen examined had been prepared by long boiling of a soda-solution of the original pigment, but it probably contained some unaltered turacin. In this modified spectrum a third black band has made its appearance in the orange, between D and C.

Composition of turacin.—The volatile constituents of turacin are carbon, hydrogen, nitrogen, and oxygen, in what proportions I shall presently state. It contains no sulphur. The ash or non-volatile constituents of the new pigment have also been submitted to a careful examination.

Turacin may be dried at 100° without change; but at a considerably higher temperature its surface-colour alters, becoming bluish and then a dull green. Afterwards it shows some symptoms of fusion, giving off a violet vapour resembling that of iodine; it finally burns away, leaving a greyish-black ash.

The close resemblance of turacin to cruorin induced me to test at once, in the ash of the new colouring-matter, for iron, the characteristic metallic constituent of the pigment of the blood, and of its derivatives. The ash of turacin was dissolved in nitric acid, excess of sodic acetate added, and then potassic ferrocyanide. Much to my surprise, instead of the deep blue *ferric* ferrocyanide, a copious purple-brown precipitate of *cupric* ferrocyanide made its appearance. Not only was copper present, but there was so much of it that it could be detected by its spectrum when the ash of a few red barbs of the original feathers was moistened with strong hydrochloric acid and exposed on a platinum-wire to the flame of a Bunsen burner.

This detection of copper in the colouring-matter was so extraordinary that it became necessary to sift the matter thoroughly. The idea that a preservative solution containing copper had been used in dressing the skins of the birds suggested itself; but this notion was soon proved untenable; for there is no copper in any part of the skin save in the red feathers, and in these feathers themselves the presence of copper is strictly confined to the red barbs. Even barbs that are partly red and partly black contain no copper in their black parts, and abundance in those which are red. Moreover, as acids do not wash out the copper from the feathers, and the most severe chemical treatment, short of actual destruction of the pigment itself, does not remove it from the prepared and pure turacin, it is evident that this metal, copper, is an integral constituent of the substance under investigation. Some idea may be formed of the intimate union subsisting between the copper and the other constituent elements of the colouring-matter, from the observation that turacin, dissolved in oil of vitriol and reprecipitated by excess of sodium acetate, suffers by this treatment no loss of copper.

The different parts of eighty-seven red feathers of *Corythaix albocristata* have been carefully examined. From the red barbs of these a considerable quantity of turacin was prepared, while their shafts were submitted to special dissection. The clear horny parts, or quills proper, at the base of each feather were cut off and separately incinerated; so also were the upper parts or shafts of the eighty-seven feathers, and, in like manner, the membranes found in the quills. There was no copper in the ash of the eighty-seven quills, and none in that of the membranes; but a very minute trace was recognized in the ash of the shafts.

There is therefore no possibility of any mistake having occurred as to the copper present in the red parts of the feathers of the Touracous. It cannot have been introduced in any preservative solution, for it would then be found in the black parts of the web as well as in the red; it cannot be an artificial dye, for birds bred in captivity acquire the cupreous pigment naturally*; it cannot be an accidental and unnecessary constituent of the red colouring-matter; for not only is it impossible to remove this metal from the pigment, but the proportion of copper present in the turacin obtained from different species of Plantain-eaters remains constant. I will now state what this proportion is.

In my earliest analysis of turacin I employed a specimen which had been precipitated by acetic acid from the alkaline extract of the feathers. Now, on burning some turacin thus prepared, I found that it left a very considerable amount of ash, nearly twice as much as in subsequent experiments where hydrochloric acid had been used as the precipitant of the pigment. Some calcium, magnesium, and ferric phosphates had obstinately adhered to the precipitated turacin, and increased to a marked extent its normal quantity of ash. The same salts accompany the colouring-matter of blood with similar tenacity. But it was soon found that the new pigment might be obtained in such a state of purity as to leave no other ash when burnt than nearly pure cupric oxide, the 7 per cent. of phosphates &c. having been previously removed by the action of hydrochloric acid without any change in the turacin itself. In the analyses which follow, turacin precipitated by hydrochloric acid was employed; the amount of ash other than cupric oxide will be seen to amount to about 1 per cent. only of the substance analyzed. I may add that even this residual impurity may be completely removed by the further employment of hydrochloric acid.

Analysis.	Turacin taken.	Total ash.	Ash per cent.
i.	·1293 grm.	·0108	8·35
ii.	·0558	·0048	8·60

	Turacin taken, corrected for ash.	CuO obtained.	CuO per cent.	Cu per cent.
iii.	·125	·0090	7·20	5·75
iv.	·061	·0045	7·38	5·89
v.	·053	·0040	7·55	6·03
vi.	·1553	·0115	7·41	5·91

Some difficulty was experienced in determining the nitrogen contained in turacin. The first combustions were made with soda-lime; but attempts to obtain, with the ammonia evolved, a satisfactory platinum-salt were unsuccessful. The NH_3 is accompanied by a substance which reduces the platinic chloride. More satisfactory and accordant results were secured when the ammonia evolved by turacin on combustion with soda-lime was received into standard sulphuric acid, and the amount of this acid thereby neutralized ascertained by a standard soda-solution. Finally, however, a modification of DUMAS's absolute method of determining nitrogen as gas was adopted: the method was as follows.

The substance, dried at 100°, was burnt with cupric oxide in a combustion-tube 2 feet in length, in which was contained, at its remote end, 6·5 grms. of pure sodium bicarbonate. Next to this was a layer of cupric oxide, then the mixture of turacin and cupric oxide. The rest of the tube was occupied by cupric oxide and 6 inches of clean reduced copper turnings. After clearing the apparatus of air by decomposing part of the sodium bicarbonate, the combination was commenced, the gases being delivered into a eudiometer standing over mercury, and partly occupied with a layer of caustic potash solution. The combustion finished, the tube was swept out by decomposing the remainder of the bicarbonate. The eudiometer and its contents were transferred to a vessel of water, and the pure nitrogen gas it contained read off with the customary precautions.

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* Private contribution from J. J. MONTEIRO, Esq., Dec. 10, 1867.

The following results were obtained in three analyses:—

Analysis	vii.	viii.	ix.
Observed volume	47·6 millims.	53·8 millims.	50·2 millims.
Volume corrected for calibre and meniscus	47·14 millims.	53·51 millims.	49·8 millims.
Temperature of gas	7°·0 C.	8°·1 C.	13°·0 C.
Barometer	739·0 millims.	733·75 millims.	753·6 millims.
Temperature of barometer . .	13°·3 C.	16°·1 C.	15°·0 C.
Water-column	497·9 millims.	495·2 millims.	495·3 millims.

The observed volume of nitrogen was also corrected for the tension of aqueous vapour, and the barometric reading for expansion of the brass scale. The usual formula of calculation was adopted,

$$v'=\frac{v\left(b-\frac{b_1}{13{\cdot}596}-b_2\right)}{760(1+{\cdot}00366\,t^{\circ})},$$

where

v represents the observed volume corrected for calibre and meniscus.
b the height of the barometer corrected for expansion.
b_1 the water-column in the eudiometer.
b_2 the tension of aqueous vapour at t° C., in millims.
t° the temperature of gas.
v' the true volume of gas in millims. (1 millim. =·1786 cub. centim.)

The following are the final results of the three nitrogen-determinations, vii., viii., ix.:—

	vii.	viii.	ix.
Turacin taken	·1445	·1665	·1604
Turacin, corrected for ash	·1431	·1648	·1588
Volume of nitrogen in cub. centims. at 0° C. and 760 millims. bar.	7·485	8·385	7·864
Weight of this nitrogen	·00939	·01052	·009866
Percentage of nitrogen	6·56	6·38	6·21

The determinations of carbon and hydrogen in turacin were made by burning the substance with cupric oxide containing some lead chromate, reduced copper turnings being placed in the anterior part of the tube. Every precaution was taken in these combustions to ensure trustworthy results, especially as, on account of its rarity and costliness, the amount of material burnt was necessarily small.

Analysis	x.	xi.	xii.	xiii.
Turacin taken	·1040	·1400	·0835	·1937
Turacin, corrected for ash .	·1030	·1385	·0825	·1916
CO_2 obtained	·2065	·2780	·1635	·3828
H_2O obtained	——	·0670	·0390	·0870
Percentage of carbon . .	54·66	54·75	54·06	54·49
Percentage of hydrogen .	——	5·38	5·21	5·06

I have gathered into the following Table the percentage results deduced from the analyses above given:—

Carbon.	Hydrogen.	Copper.	Nitrogen.
54·66	......	5·75	6·56
54·75	5·38	5·89	6·38
54·06	5·21	6·03	6·21
54·49	5·06	5·91	
54·49	5·22	5·90	6·38

If, however, we exclude the low percentage of carbon (54·06) obtained in one case where the amount of substance taken was insufficient to secure an accurate result, we may deduce the following mean percentages as representing the centesimal composition of turacin dried at 100° C.:—

Carbon	54·63
Hydrogen	5·22
Copper	5·90
Nitrogen	6·38
Oxygen (diff.)	27·87
	100·00

If we assume that one molecule of turacin contains one atom of copper, we are led to conclude that the relations between its constituents may possibly be represented by the empirical formula

$$C_{50}H_{56}CuN_5O_{19},$$

which demands the following percentages:—

		Theory.	Experiment. (Mean.)
C_{50}	= 600·0	54·87	54·63
H_{56}	= 56·0	5·12	5·22
Cu	= 63·5	5·81	5·90
N_5	= 70·0	6·39	6·38
O_{19}	= 304·0	27·81	27·87
	1093·5	100·00	100·00

I do not wish to attach great importance to the above formula for turacin; but it certainly represents the analytical results closely, and possesses, in its atom of copper, an element of control similar to that of a metallic salt. In its permanence and its constancy of composition, turacin is separated widely from complex bodies like the albuminoids, which in many particulars it resembles; for it must be here noted that the analyses above given have been made with different specimens of turacin—some with specimens from *Musophaga violacea*, but in most instances with the pigment from the *Corythaix albocristata*, or *C. porphyreolopha*. Notwithstanding this diversity of origin, and certain changes in the modes of preparation, the analytical results have been remarkably concordant.

Affinities of Turacin.—In its colour, in its absorption-spectrum, and in some of its other characters, turacin corresponds closely with the scarlet cruorin of blood, yet it contains no iron, or, at most, an inappreciable trace of this metal. Iron, however, exists to the extent of between 6 and 7 per cent. in hæmatin, the chief derived colouring-matter obtained from blood, and is doubtless a constituent of the original cruorin; yet if, in turacin, the iron of cruorin is replaced by copper, there are other and wider differences of composition and deportment between the two pigments, which prevent us from regarding turacin as a *copper cruorin.* Moreover turacin does not seem to occur in corpuscles, but to be homogeneously distributed in the barbs, barbules, and crochets of the red feathers in which it occurs.

Turacin seems to characterize the closely allied genera *Musophaga* and *Corythaix.* These birds, though with the other Touracous distinctive of the African Ornis, are not common; and in consequence the supply of turacin for experimental purposes is very limited. I have not detected it in any of the other red-plumaged birds which I have examined. The quantity of turacin in a single bird is small. It is most abundant at the pairing-season, and the bridal plumage of a *Corythaix albocristata* generally yields from two to three grains of the pigment. One bird, then, may contain in the colouring-matter of its wings nearly ·2 of a grain of metallic copper.

Turacin is the first animal or vegetable pigment containing copper as an essential constituent which has hitherto been isolated; yet traces of copper have been repeatedly found in both animals and plants. It was detected by HARLEN in the blood of certain Ascidia and Cephalopoda. It occurs in *Limulus cyclops*, *Cancer pagurus*, *Acanthias zeus*, and *Conger vulgaris*, its quantity being in inverse ratio to the quantity of iron present. The blood of *Helix pomatia* contains much copper, the part of the ash insoluble in water yielding 2·57 per cent. Many chemists have detected minute traces of copper in human blood; and twenty years ago DESCHAMPS arrived at the conclusion that it is normally contained in the blood of man and animals. ODLING and DUPRÉ have indeed subsequently detected copper in flour, straw, hay, meat, eggs, cheese, and other articles of food. It has been supposed that the copper detected in some of these substances has been introduced in the course of analysis by the use of brass burners and retort rings; but these in most cases are a purely imaginary source of error. It is not difficult to perceive whence the Touracous derive the copper which their red feathers contain; and I have actually succeeded in obtaining unmistakable indications of copper from the ash of three fruits of a plantain, the common *Musa sapientum*. There is, of course, still room for experiment and further observation in this direction. Researches as to the source of copper whence vegetables assimilate it, the occurrence of ores of copper near the habitats of the Touracous, and its detection in the articles of food supplied to these birds when kept in captivity will doubtless lead to interesting results. The whole subject of the occurrence of copper in animal products is fraught with physiological as well as chemical interest.

In conclusion I must express my obligation for the assistance afforded me, during the progress of the present inquiry, by those friends whose names I have already mentioned, and by others who have rendered me special aid. To Dr. J. H. GLADSTONE I am indebted for the drawings of spectra which accompany this paper; to PHILIP COURT, Esq., of Port Elizabeth, for an ample supply of Touracous when the stores of the London natural-history dealers were exhausted; and, especially, to my assistant, Mr. B. J. GROSJEAN, for the laborious and conscientious care with which he has executed nearly the whole of the analytical work involved in the present research.

XXII. *On the Thermal Resistance of Liquids.* *By* FREDERICK GUTHRIE. *Communicated by Professor* TYNDALL, *LL.D., F.R.S.*

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I. *Introduction.*

§ 1. THE passage of heat through matter has been mainly examined in reference to the diathermancy of solids, liquids, and gases to radiant heat, and to the conduction of contact-heat through solids and gases. The conduction of contact-heat through liquids forms a chapter in heat transference which has not hitherto received as much attention from experimental physicists as it merits.

§ 2. In the following pages I have the honor of submitting to the Royal Society certain experimental results and considerations to which I have been led during an investigation of this subject. These results are necessarily incomplete. The inquiry is fraught with very numerous and considerable experimental difficulties; but I venture to hope that such as the results are, they may be found useful to those who shall hereafter pursue the subject with greater skill and more perfect appliances.

§ 3. It need scarcely be stated that the great majority of the experimental results obtained do not appear in this Memoir. Such results, though of great interest to the experimenter and invaluable for his guidance, have of course been suppressed, having been superseded during the investigation by those obtained through the application of successive improvements to the apparatus employed.

§ 4. I have been induced to pursue this investigation with some perseverance, because I am convinced that it is by means of liquids rather than of solids that we are destined to gain ultimately an exact experimental determination of the conduction of heat in all cases. By their means we shall gather data concerning the conductive indices or thermal resistances of the elements, and be able to determine the effect on such resistance caused by the change of chemical nature and of molecular construction of bodies.

§ 5. These data will be furnished by liquids rather than by solids, because no two specimens of the same solid substance are physically identical. It would be difficult, perhaps impossible, to point to a single solid the material of which has not, at some time or other, been in the liquid or gaseous state. Now, in the overwhelming majority of instances, the parts of the body, at the moment of solidification, arrange themselves in some definite form, either as the rectilinear crystals of definite chemical proportion, or as those more complex forms wrought together by living beings. And it is owing to the varying conditions under which such solidification takes place, that the structure of different specimens of solid matter bearing the same name is so various.

§ 6. Rate of solidification as affected by temperature and pressure, and the presence of foreign bodies which may subsequently be entirely withdrawn, are instances in point in "dead" matter; while the structures of plants and animals are so inconstant that every two specimens of the same organized body differ appreciably from one another even in texture. No solid substances are homogeneous. Metals all show irregular crystallization. The hardest gems have cavities. There are interstices between parts of a crystal which are in optical contact. In short, no sooner does a gas or liquid assume the solid form than it ceases to be homogeneous.

§ 7. But under like external circumstances, two equal volumes of the same liquid are identical. No examination can distinguish the one from the other. The only appreciable difference, the only individuality is that of place.

§ 8. One of the chief difficulties to be overcome in studying the thermal resistances of liquids meets us on the threshold, and arises from the expansion of liquids by heat. If the bottom, sides, or interior of a liquid mass be heated, the whole liquid is gradually set in motion owing to the expansion of the heated portions; and the heat-effects observed at other places in the mass are chiefly due to the convection of heat by the moving liquid.

§ 9. To get rid of such currents two methods are possible, (1) to heat the upper surface of the liquid, (2) to cool the lower one. For by either of these means, the hotter portions of the liquid always rest above the cooler ones, so that no currents can be produced. The two methods should give equally correct and, indeed, in many cases, identical results; in all cases results easily comparable. The choice is a matter of convenience. I have preferred the first, because it is more easy to control exact and constant temperatures of any considerable range when above, than when below the atmospheric temperature.

§ 10. It is clear that when a mass of liquid contained in a vessel is heated from above, the heat will be communicated to the containing vessel. If the latter conduct heat better than the liquid, heat will travel down it more rapidly than down the liquid, and the result will be the establishment of currents such as are shown in Plate LXV. fig. 1 *a*. If the vessel be a worse conductor than the liquid, it will withdraw from the liquid in contact with it a portion of the heat which has been conducted from above; so that again currents will be established as in Plate LXV. fig. 1 *b*. In both cases, therefore, the apparent conduction of the heat by the liquid will be modified by the different conducting-power of the vessel. But as the mass of the liquid varies as the cube, while the surface of the vessel varies only as the square of the linear dimension, the disturbing influence of the vessel's walls may be diminished to any amount by increasing its size. Vessels of great size can, however, only be employed for a few liquids.

II. *Sketch of former Experiments.*

§ 11. The experiments which have been hitherto performed on the conduction of heat through liquids are briefly the following:—

§ 12. Count RUMFORD* froze some water at the bottom of a cylindrical vessel. Upon this he poured a known quantity of warm water. After a time the liquid contents of the vessel were again determined, and the increase was found to be so small that it was concluded to arise wholly from the direct contact of the ice with the warm water in the first instance. Count RUMFORD also took two cylinder glasses containing ice frozen to the bottom. Into one he poured boiling water, and into the other an equal weight of water at 0° C. In both cases the ice soon became covered with a layer of water at its maximum density (4° C.). After a time the ice was removed from both vessels and weighed. From the result the experimenter concluded that the quantity melted was nearly the same, and that consequently the water did not conduct the heat.

§ 13. Dr. TH. THOMSON† gently heated from below a column of coloured water covered with a column of colourless water, and found that the heat ascended even when no coloration of the upper water-layer took place, and when therefore no sensible diffusion or convection occurred. Such an experiment must be unsatisfactory for reasons already mentioned, unless indeed the water have the initial temperature of between 0° and 4° C., and the lower portion be heated to not above 4° C. In this case only can the water possibly remain in equilibrium, the denser layers being then the lower ones.

§ 14. Mr. J. MURRAY‡ employed a hollow cylinder of ice as the vessel to contain the liquid under examination. In such a cylinder he placed successively mercury and oil at 0° C. The upper surface of the liquid was heated by means of a vessel of water at 100° C., supported in some cases a little above the liquid, in others in actual contact with it. The object of the ice-cylinder was to get rid of conduction, because the ice on receiving heat does not become warmer,—it melts. But, as pointed out by M. DESPRETZ, the existence of the melted ice and the partial destruction of the vessel complicate and in a great measure invalidate the results. Indeed, in some respects, ice is the worst substance which could be chosen, on account of the distortion of the results due to the great latent heat of water and the small specific heats of mercury and oil. But although quantitative results were out of the question, Mr. MURRAY succeeded in establishing the fact, which we shall find confirmed, that mercury is a better conductor of heat than oil.

§ 15. The question was in this unsatisfactory state when M. DESPRETZ published his first memoir§ on the subject. M. DESPRETZ filled with water a wooden cylinder painted internally 1 metre high and from 0·218 to 0·405 metre internal diameter, the thickness of the sides being 28 millimetres. At equal intervals down the axis of the cylinder were the bulbs of horizontal thermometers whose stems pierced the side of the cylinder. The column of water was heated from above by means of a copper vessel, the bottom of which was in contact with the upper surface of the column. Into this vessel fresh portions of hot water were poured at intervals of from four to five minutes. After between thirty and sixty hours the thermometers became stationary, and from the degrees of heat which they marked, the experimenter concluded that the temperatures (above the air) were in geometrical progression (the intervals being equal), and that accordingly the law of conduction for water is the same as that for solids. M. Despretz found that the conductivity of salt water is sensibly the same as that of fresh. Measured in this way, it appeared that water had a conductivity about $\frac{1}{100}$ that of copper.

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* RUMFORD, Essays, vol. ii. p. 199.

† NICHOLSON'S Journal, vol. i. p. 81.

‡ Arch. vol. xlii. p. 195; also GEHLER'S Wörterbuch, Art. Wärme.

§ DESPRETZ, Ann. de Chim. et de Phys. 1839, p. 206. Also Comptes Rendus, 1852, p. 540.

§ 16. It was found in these experiments that the axis of the cylinder was hotter than the parts towards the circumference, and that the interior of the wall of the wooden cylinder was cooler than the surface in contact with the liquid. These circumstances appear to detract somewhat from the value of M. Despretz's results, because the existence of inequality of temperature invariably points to the existence of vertical currents. Granted that the wood conducts worse than the water, what is the consequence? Not that the wood is of no influence, for a portion of the heat of the water must necessarily be given to the wall which it touches, albeit more may be given to the water below, so that currents arise according to § 10, Plate LXV. fig. 1 *b*.

§ 17. Another source of error, as it appears to me, in these experiments, lies in the intermittent manner in which the hot water is renewed in the source of heat. The time required to produce a given effect must certainly be thereby very materially increased. For when a quantity of hot water is poured in and allowed to stand, not only is the top of the conducting column heated but the bottom of the heating mass is cooled, the two quickly assume nearly the same temperature, which is below that of the water originally added. When, therefore, a fresh supply of hot water arrives, its heat has to traverse a series of strata of water, each of which is at a lower temperature than it would have been if the supply of hot water had been continuous,—that is, if the upper layer of the column had been maintained at a maximum temperature instead of being only momentarily raised to that temperature by each successive addition of hot water to the upper vessel.

§ 18. It seems, indeed, clear that the condition of M. Despretz's column, after the thermometers have become stationary, results from the establishment of thermal equilibrium between the continual accession of heat from above downwards, and the escape of that heat through the sides of the containing vessel by radiation and atmospheric conduction; otherwise it is impossible, with our present knowledge of the nature of heat, to explain the fact observed, that even after sixty hours the lowest thermometers show no increase of temperature in the lower strata of the column.

III. *Description and use of the Diathermometer.*

§ 19. The object immediately proposed in the following investigation was to determine the relative and absolute thermal resistance offered by a given thickness of a given liquid in a given time, when the liquid has a given temperature, and when the temperature difference between the liquid and the source of heat is known. To effect this, an apparatus had to be devised which would be applicable to many different liquids, and to solids, and which would be as free as possible from the disturbing influences already pointed out.

§ 20. The extreme sensitiveness of the thermo-electric pile cannot be made use of directly in experiments of this nature. The pile leaves little to be desired where momentary effects of radiant heat are concerned; but it is obviously inapplicable where the quantity of heat has to be considered, as must be the case wherever time is an element of the result.

§ 21. After many trials I have adopted, for the present, the form of instrument described below, and which I believe will be found to answer for a great variety of conditions. The instrument may be called a "Diathermometer." Although it has been hitherto employed exclusively for liquids, it is equally applicable to solids. The apparatus has been skilfully constructed by Mr. W. Ladd, of Beak Street, London. The experiments were made partly in the theatre of the London Institution, and partly in the cellar-passage beneath it. Two conditions essential to satisfactory results, are freedom from vibration and uniformity of atmospheric temperature—conditions difficult to obtain in our metropolis and climate, but which were, I think, as nearly as possible satisfied by the solid foundation of the building and the large volume of still air, in or beneath which the experiments were performed.

§ 22. Plate LXV. fig. 2, shows the diathermometer in almost actual size in elevation. Plate LXV. fig. 3 is a view of the entire arrangement of the apparatus. The whole of the diathermometer is of brass, with the exception of the bases of the cones to be described immediately. Upon a mahogany slab, U (fig. 2), there rests a tripod stand, S, supported on two screws, T, T, and the point N. From one end of the stand above N there is fixed the triangular vertical prism M, which terminates above in a very accurately cut screw, K K. Exactly fitting M is a sliding collar, H, to which is screwed the bracket G. The arm F is screwed firmly upon G. One end of F is pierced so as to allow the screw K K to pass through and is clasped by the nut I J, which works accurately upon the screw K K. The head of the nut I, where it is in contact with the arm F, is graduated into 10ths and 100ths. Upon the arm F, beneath the graduation of the nut, is an arbitrary mark, R. The other extremity of F carries a collar, into which is screwed the brass cone A, also provided with a collar, W. The cone A is made of sheet brass, and has the size and shape shown in the figure. Its lower or flat surface is covered with a thin sheet of platinum, which is soldered to the brass. The diameter of the platinum base is 53·34 millims. The neck of the conical flask (A) is provided with a cork (E), through which pass two glass tubes, C and D. The tube C reaches to 0·5 millim. from the bottom of the cone. The tube D is open immediately beneath the cork. Exactly facing A is a perfectly similar cone, B, which is screwed into the centre of the tripod stand, S. The lower cone is also faced with platinum. The neck of B is furnished with a cork, P, through which passes the vertical tube Q, open at both ends. This portion of the apparatus must be scrupulously air-tight. The lower end of Q dips into a wide vessel of coloured water, and carries a paper scale divided arbitrarily, but into exactly equal divisions.

The lower cone and tube form in fact an air-thermometer, the liquid in the stem of which may be adjusted to any height.

§ 23. The platinum surfaces of the cone bases are ground optically flat and polished*. When breathed upon and brought into contact, they fit one another so exactly that the one may be almost lifted by the other, owing to their adhesion. Before being used, they are washed in succession with hot caustic soda, nitric acid, alcohol, and water.

§ 24. It is clear that if the micrometer-screw is read when the cones are in actual contact, and again when they have been removed to some considerable distance (say 10 millims.), we know how much the screw must be turned to give a motion of 1 millim. In my apparatus 1·06 turn of the screw corresponds to 1 millim., and as the screw-head is divided into 100 parts, it is easy to adjust the distance of the platinum faces from one another to 0·005 millim. The platinum faces are brought into an exactly horizontal position by placing a spirit-level on the lower one, and adjusting by means of the screws T, T. A thick ring of vulcanized caoutchouc (X) presses the tripod stand to the board.

§ 25. The upper cone is then brought down to the required distance from the lower one, and the flat cylindrical interval between the two is filled by means of a pipette with the liquid through which the heat has to pass. When the distance (δ) between the faces is small (say 0·5 millim. to 1 millim.), the edge of the liquid is sensibly vertical, and the eye judges very accurately whether the interval is underfilled or overfilled. But at greater distances (from 2 millims. to 12 millims.) the lower portion of the liquid disk bulges out in consequence of the weight of the liquid, although both upper and lower face remain perfectly wetted. Thus at a distance of 6·6 millims., water shows an appearance as in fig. 4, Plate LXV. The mere filling of the interval as full as it will hold is then a very imperfect guide. In such cases small strangulated pipettes are used (fig. 5, Plate LXV.), which deliver a volume of liquid exactly equal to the volume of the interval when the faces are 0·5 millim. or 1·0 millim. apart. By this means, although the edge of the liquid be curved, we at all events know that the volume of the liquid is the same as if it were vertical and straight†.

§ 26. Let us imagine that a known thickness of liquid is between the cones, that the capacity of B is known, that the tube Q has been calibrated, that the temperature of the air has been ascertained, that the height of the liquid in Q is noted, that the barometric pressure has been observed, and that the height of the column of water above the surface in the reservoir has been also measured. If now a current of hot water of known temperature is led through the tube C, the lower surface of A at once assumes and is continually maintained at a known temperature. The heat gradually

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[*] Held obliquely, the image of a straight line seen on the base of the cone coincides with a straight edge, however the cone may be turned on its axis.

[†] It is noteworthy how remarkably the cohesive preeminence of water appears in these experiments. Other liquids can be obtained in disks of 4 millims. to 5 millims. only with great care: water may be got in disks of 8 millims., or even 12 millims. It will be remembered that I have elsewhere shown that of all liquids water has the greatest drop-size (Proceedings, Royal Society, 1864). This fact is also to be attributed to the superiority of that liquid in cohesion.

travels downward through the liquid L, warms the platinum face of B, expands the air in B, and depresses the water in Q.

§ 27. The arrangement for leading a current of water of constant temperature through A is shown in fig. 3, Plate LXV. A tinned iron cylindrical vessel containing the water, 1, about 1 metre high and 30 centims. diameter, is heated by a gas-lamp, 2. The gas supplying the lamp passes through the thermostat, 3. Supported near the bottom of the cylinder is a perforated conical mixer, 4*. In the immediate neighbourhood of the bulb of the thermostat is the bulb of the standard thermometer, 5, a small suspended beaker glass, 6, and the shorter limb of the siphon tube, 7. The longer limb 8 of the siphon may be introduced into the funnel 9 connected with the tube C of the diathermometer. The diathermometer itself, 10, is firmly clamped upon a substantial three-legged camera-stand, 11, and a wooden screen, 12, is placed between the lamp and cylinder, 2 and 1, and the diathermometer. A tube attached to the tube D of the diathermometer conveys away the warm water which has passed through the cone A. When one experiment has been made and the instrument has been readjusted by passing cold water through A, the cone A is emptied by forcing air through D; by this means there always remains a film of water on the bottom of A of about 0·5 millim. in thickness.

§ 28. Let us suppose that an experiment has to be made, that the diathermometer has been adjusted, and that the temperature in 1 is the required temperature. The siphon 7, 8 is hung away from the diathermometer and the water is set running through it. About 5^s before the appointed time, the beaker, 6, full of warm water is brought to the edge of the funnel, 9. At the appointed time it is emptied into the funnel, into which is immediately placed the end of the siphon, 8. A continual flow of hot water takes place through the cone A, the base of which is therefore thenceforth maintained at a temperature a given number of degrees above the temperature of the air, that is, above the temperature of the liquid, L.

§ 29. The thermometer used was a standard Kew thermometer, the error of which was determined. The readings subsequently given are all reduced to Centigrade.

IV. *Sources of Error and Corrections.*

§ 30. It is clear that when the hot water passes through the siphon, 7, 8, into the cone A, the water in A is somewhat cooler than in 1, in consequence of the radiation from the siphon and cone and of the atmospheric convection. It is necessary therefore to estimate this loss of heat in order to know at what temperature the water in 1 must be kept, so that the water in A may have the required temperature.

§ 31. The temperature of the air, T, being 18°·16 C., it was found that,

When the temperature in 1 was	28°·16	38°·16	48°·16
Then ,, ,, A ,, ...	27·88	37·51	46·40
Loss	0·28	0·65	1·76

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* For description of thermostat and mixer, see Phil. Mag., July 1868.

Thus, in order to get in A a temperature 10° above the atmospheric temperature, T, the water in 1 must be heated to $T+10\cdot28$. To get an excess of 20° in A, the water in 1 must be heated to $T+20\cdot65$, and so on. From these three values, which include almost the entire range of temperatures which I have employed, the intermediate values can be interpolated when required. These values may vary slightly with the atmospheric temperature at the time, but such variation is within the limits of observational error*.

§ 32. *Radiation.*—The question is a vital one, whether, and if so, what proportion of the effect produced in the lower cone is due to radiation through the liquid. If radiation takes place in such a manner as to completely penetrate the liquid and reach the lower platinum surface, the effect would inextricably complicate the phenomena; for while some of such radiant heat would be reechoed upwards and downwards between the cones, a portion would be absorbed by the lower plate, and this would not only augment the expansion of the air in the lower cone, but being shared by the lower part of the liquid (L) in contact with it, currents would be formed and the results vitiated. Such effect might indeed be to a great degree diminished by making the face of the lower cone of fluor-spar or even of glass. But the great thermal resistances of such substances, compared with that of a metal, would more than counterbalance the possible benefit to be derived from their greater diathermancy.

§ 33. Actual experiment, however, showed that the effect of radiation was inappreciably small.

§ 34. It will be admitted that radiant heat would pass with a velocity so great that the time-lapse between its emission from the upper plate and its effect upon the lower cone would be inappreciably small. The following results with water show that, under the following conditions, the time-lapse between the influx of water into A and the commencement of the depression in Q was pretty constant and considerable.

T=Temperature of air or initial temperature of liquid $=21°\cdot39$
T_1=Temperature of water in A . . . . $=31°\cdot39$
ΔT=Temperature-difference . . . . $=10°\cdot00$
t=Time required to produce first effect in Q.
δ=Thickness of liquid, L.

	$\delta=2$ millims. s	$\delta=3$ millims. s
(1)	$t=6$	$t=10$
(2)	$t=7$	$t=10$
(3)	$t=7$	$t=11$
(4)	$t=5$	$t=11$
(5)	$t=7$	$t=10$
Mean	$t=6\cdot4$	$t=10\cdot4$

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* Strictly the temperatures in 1 should be observed when the temperature in A is fixed; the difference between the results so obtained and those given is vanishingly small.

At greater distances, as we shall see, t may be as much as 20^s. This time-lapse cannot be due to the obstruction caused by the metal bases; for, as hereafter shown, when nothing intervenes between them, that is, when they are in actual contact, the lapse of time between the influx of hot water into A and the depression in Q is immeasurably small. Even when $\delta=1$ millim. the time-interval t is sensible.

§ 35. These experiments alone might be considered sufficient to show that at these intervals, at all events, and with water the effect of radiation is practically nothing. The question, however, is so fundamentally important to the investigation that it was examined in another way. The experiment was made as before, with water between the plates, then a disk of Swedish filtering-paper exactly of the same size as the platinum faces was introduced, and the experiment was repeated. In these experiments not only was the time-lapse required for the first effect noted, but the total depression in Q after 1, 2, and 3 seconds was observed. Let these depressions, measured in millimetres, be ΔH_1, ΔH_2, ΔH_3 respectively. We need not reduce these linear depressions to thermal units to recognize the smallness of the effect produced by the interposition of the paper.

$$T=21^\circ{\cdot}22$$
$$T_1=31^\circ{\cdot}22$$
$$\Delta T=10^\circ{\cdot}00$$
$$\delta=3 \text{ millims.}$$

	t.	ΔH_1.	ΔH_2.	ΔH_3.
	s	millims.	millims.	millims.
Water without paper disk.	10	47·77	77·21	90·52
	10	48·26	79·62	91·00
Mean	10	48·01	78·41	90·76
	s	millims.	millims.	millims.
Water with paper disk.	10	46·81	77·21	88·59
	10	47·27	75·76	86·67
Mean	10	47·04	76·48	87·63

If we take into account the great thermal resistance of paper, and further, that the absolute bulk of the matter through which the heat has to pass is increased by the introduction of the paper, we are again led to the conclusion that the effect of radiation is negligible.

§ 36. In a previous experiment with another set of cones having brass faces, similar results were obtained. The distance between the cones was about 2·1 millims., but it was not exactly measured; neither was the temperature of the air nor the time-lapse t. The depression is given up to the end of 10 minutes.

$$T_1=23^\circ{\cdot}06$$
$$\Delta T=14^\circ \textit{ circa.}$$
$$\delta=2{\cdot}1 \text{ millims. } \textit{circa.}$$

	Water alone. millims.	Water with paper disk. millims.
ΔH_1	113·41	108·58
ΔH_2	203·61	203·61
ΔH_3	243·71	243·71
ΔH_4	267·84	262·91
ΔH_5	282·34	277·39
ΔH_6	291·97	287·04
ΔH_7	301·62	296·69
ΔH_8	308·76	304·04
ΔH_9	313·69	311·18
ΔH_{10}	316·10	316·10

The absolute coincidence of some of these numbers to the second place of decimals arises from the arbitrary divisions on the scale being reduced to millimetres, and is not therefore a measure of the strictness of the accord. Nor can these results be compared with those of § 34 for the reasons given; but they bear strong independent testimony to the absence of sensible radiation.

§ 37. As, however, Dr. TYNDALL has deduced from his experiments on radiant heat that water (or at all events a saturated solution of chloride of sodium) is of all transparent liquids examined the most athermanous, it was considered advisable to examine one or two other liquids. On examining amylic alcohol and oil of turpentine in this manner, the depression in Q, when the liquids were alone, was found to be even more strictly equal to that produced in the presence of a paper disk than was shown by water.

The most recent researches of Herr MAGNUS[*] entirely confirm these results. This experimenter has shown that a certain proportion of non-luminous heat-rays which radiate at an angle of 35° from the surfaces of solids and liquids heated to 100° C. undergo polarization, and that consequently a certain proportion of the heat radiated in this way emerges from beneath the geometrical surface of the body. It would result from this conclusion that all the substances examined are, up to a certain thickness, diathermanous. Such superficial diathermancy is quite consistent with the perfect athermancy of the same substances when employed in sheets or films of the utmost attainable tenuity.

§ 38. The same experimenter has, indeed, shown that when a liquid is raised throughout to 100° by maintaining its lower portion at that temperature, precisely the same phenomena of radiation and polarization of the heat are observed, whether the bottom of the vessel containing the liquid be brightly polished or covered with lampblack. It results from these experiments that the liquids examined, namely rape-oil, resin, wax, glycerine, paraffin, in layers less than 1 centimetre[†] in thickness, are perfectly athermanous to heat of 100° C. Now if 10 millims. of a liquid are athermanous to a heat-difference of, say, 80°, may not 3 millims. well be athermanous to a heat-difference of 10°?

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[*] Monatsbericht der Königlich preussischen Akademie der Wissenschaften zu Berlin, April 1868, p. 249.

[†] The liquid was contained in a metallic dish 1 centimetre deep; the exact thickness of the liquid layer is not stated.

§ 39. *Diffusion.*—It is well known that when two unequally heated portions of the same liquid, or of two miscible ones are mixed, a state of thermal equilibrium between the two is established, and a temperature results intermediate between those of the mixed liquids, and dependent upon their temperatures, masses, and capacities for heat. If such experiments stood alone, it would be difficult, either by the dynamic or the conditional theory of heat, to disprove the assertion that no interchange of heat takes place between particle and particle,—that each particle maintains its original temperature, and that, being mutually diluted, the effect (for instance on the mercury of a thermometer) is the resultant of two unequal but continual efforts.

§ 40. But the fact that substances in contact establish thermal equilibrium without mutual interpenetration, shows that the first method of heat equalization may and does take place. The question, however, still remains:—Is the equalization of temperature instantaneous when two liquids of unequal temperature are perfectly mixed? When a vessel of cold water is placed over a flame, may not the water at the bottom which has the temperature of the bottom, diffuse into the colder water without immediately losing its temperature*? All analogy, indeed, indicates the high improbability of such an occurrence, but by no means its impossibility. The question is of importance in our present direction of research; for it may be maintained that the heat which appears at the lower cone has been conveyed downwards by the downward diffusion of the warmer liquid at the top, instigated by the difference in density of the upper and lower portions.

§ 41. To set this question at rest, the bottom of the upper cone was painted with a soluble aniline dye. Sufficient water was placed upon the lower cone to fill an interval of 3 millims., and the upper cone was brought down to that distance. The conditions of the experiment were as follows:—

$$T=13°{\cdot}3\ \text{C.}$$
$$T_1=23°{\cdot}3\ \text{C.}$$
$$\Delta T=10°\ \text{C.}$$
$$t_1=10\ \text{min.}\ (t_1\ \text{is the duration of the experiment})$$
$$t=10\ \text{sec.}$$

At the end of 10 minutes, when nearly the maximum depression had been effected, some of the liquid in contact with the lower cone was cautiously withdrawn by means of a capillary pipette. The perfect colourlessness of this portion showed that no convection due to diffusion had taken place; the only other alternative being the diffusion of the water away from the colouring-matter,—a hypothesis sufficiently improbable for us to conclude that no diffusion of the kind occurs.

§ 42. This experiment at the same time furnishes an excellent test of the trustworthiness of the instrument, for it shows the absence of convection from whatever cause.

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* A similar suggestion in regard to air, occurs in MAURY's 'Physical Geography of the Sea;' the occasion being the calm-belts of Cancer and Capricorn.

V. *Measurement of the Velocity of Heat-penetration, t.*

§ 43. The question as to the rate at which heat passes through liquids immediately involves another, namely :—Does the effect of a greater heat-difference travel faster than that of a less heat-difference? This interesting question may be easily and satisfactorily answered by means of the diathermometer. The conditions of an experiment were (with water):—

$$T=21^\circ{\cdot}39$$
$$\delta=3 \text{ millims.}$$

ΔT.	*t.*					Mean.
	(1)	(2)	(3)	(4)	(5)	*t.*
°	s	s	s	s	s	s
30·83	7	7	7	6	7	6·8
25·83	8	7	8	8	7	7·6
20·83	8	8	8	8	8	8·0
15·83	9	9	9	—	—	9·0
10·83	10	10	10	—	—	10·0
5·83	12	10	11	11	—	11·0

It appears distinctly from this Table that when the temperature-difference is greater a more rapid passage of the heat is effected, at all events when the same initial temperature T is taken. There still remains, however, a possibility that the effect may be due as much to the difference of the *quality* of the heat at the higher limit as to the extent of the range. Perhaps there may be no simpler exact means of clearing up this point than the performance of similar experiments, at times when the atmospheric temperature has greatly altered. We shall return to this point in considering the quantity of heat which traverses the liquid disk.

§ 44. When the temperature-difference is small the commencement of the effect is not well marked; hence the tendency of the observer is to overestimate the time; this error is diminished by using a very narrow tube for Q.

§ 45. Sperm-oil and glycerine were examined under the following conditions:—

$$T=26^\circ{\cdot}5$$
$$T_1=36{\cdot}5$$
$$\Delta T=10{\cdot}0$$
$$\delta=3 \text{ millims.}$$

	t.			Mean. *t.*
	s	s	s	s
Sperm-oil	17	17	16	16·6
Glycerine	11	11	11	11

We shall find subsequently that the resistances of the three liquids, water, glycerine, and sperm-oil (as measured by the number of units of heat equal thicknesses of them arrest in a given time), are in the order just written, the resistance of water being least. I have not at present sufficient data for establishing the relation between the time *t* and the resistance.

§ 46. If we had found that the time *t* required for penetration had been the same for heat of all temperatures, we should of course expect to find the time *t* proportional to the thickness δ. That this is not the case appears from the following experiment with water. The interval between the plates was raised successively from 1 millim. to 6 millims. by degrees of 0·5 millim.; at each half millimetre the time *t* was measured under precisely similar circumstances.

$$T = 26^{\circ}{\cdot}5$$
$$T_1 = 36{\cdot}5$$
$$\Delta T = 10$$

δ.	*t*.					Mean. *t*.	Δt.
millims.	s	s	s	s	s	s	s
1	4	3	3	4	3	3·4	1·2
1·5	5	4	5	5	4	4·6	1·8
2	6	7	7	5	7	6·4	2·0
2·5	8	9	8	9	8	8·4	2·0
3	10	10	11	11	10	10·4	2·8
3·5	13	14	13	13	13	13·2	2·2
4	15	16	16	16	15	15·4	3·0
4·5	18	19	19	18	18	18·4	3·6
5	20	21	21	21	22	21·0	2·8
5·5	24	24	24	24	23	23·8	3·2
6	25 (?)	26	27	28	27	27·0	

§ 47. It hence appears that the thickness and time of penetration are not directly proportional to one another, but that if one disk of water be twice as thick as another, the thicker one will delay the heat more than twice as long as the thinner one. And this fact may well arise from the one previously established, that heat of a high temperature penetrates more quickly than heat of a lower temperature. For if we imagine two simultaneous experiments in which the heat reaches the middle of the thicker layer exactly at the moment when it has just completely penetrated the thinner one, then the second half of the thicker liquid will have to resist the passage of heat from a source of lower temperature, and this, as we have seen, implies a slower passage. Neither the case where the liquid is very thin, nor that in which it is very thick, is the most favourable for determining the time *t*. In the first the margin of unavoidable error forms a large fraction of the observed time *t*; in the second the commencement of the motion in Q is so gradual that some little time may elapse before it is recognized. The instant of the commencement of a slow motion cannot be so accurately determined as that of a quick one. In fig. 6 the points of the curve 1 represent the variation of t with ΔT; those of 2 represent the variation of t with δ.

VI. *The Quantity of Heat conducted, or Measure of Resistance.*

§ 48. In order, by means of the expansion of the air in B, to measure the quantity of heat which passes through a liquid under given conditions, or to measure the resistance which the liquid offers to the passage of heat, it is necessary to know the capacity of the lower cone B, and the calibre of the different portions of the tube Q, together with the whole pressure on the air in B. A Table was formed, which being arbitrary need not be here given, showing the capacity in cubic centimetres of the different parts of Q, which was slightly conical. The lower cone B and a small portion of Q, as far as a certain point, had the volume 45 cub. centims.

§ 49. It is clear that the increase of volume in B does not directly give the quantity of heat which passes through the liquid L, because part of that heat is expended in heating the metal of the lower cone; and moreover the heated air in the lower cone accumulates towards the top of the lower cone, so that although the coefficient of air-expansion is virtually the same at all temperatures, yet there being less temperature-difference between the platinum and the air than would be the case if the air in cone B were continually mixed, the ingress of heat must be smaller and the thermal resistance of the liquid would appear too great. A certain amount of radiation from the lower cone tends in the same direction, as also does the loss of heat due to its expenditure in penetrating the cone bases. It would be nearly impossible to estimate and allow for all these errors; but they may be eliminated *en masse*. For if the cones are in the first instance brought into actual contact, and this expansion in B is measured under given experimental conditions, and if then the expansion is also measured when a liquid is inserted under like conditions, then the difference between the two effects is a true measure of the thermal resistance of the liquid, because the same errors being attached with the same signs to both determinations, do not affect their difference.

§ 50. The platinum faces of the cones were brought into actual contact by wetting their faces with mercury[*]. The quantity of mercury so introduced was immeasurably small, and its presence causes a far less error than would attend the presence of an air-film. It was found that the value of t in all cases was too small for measurement, indeed the transmission of heat appeared instantaneous; it was certainly less than $0^{s}\cdot5$. In these, as in the previous experiments, I have preferred to give the nearest whole number of seconds rather than to attempt to subdivide a second. The expansions were measured after 1, 2, and 3 min. The necessary corrections have been made in these numbers for the varying pressure in B.

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[*] For a method of wetting platinum and other metals with mercury, see a paper by the author on Drops (Royal Society Proceedings, 1864). When the cone-faces are wetted with mercury and the one face is slid upon the other, the lower cone may be weighted with from ten to twelve pounds before the two are separated.

$$T = 21^{\circ}{\cdot}22$$
$$T_1 = 31{\cdot}22$$
$$\Delta T = 10$$
$$\delta = 0.$$

ΔH, which has to be found, represents the corrected depression in millimetres.

t. s	$t_1 = 1$ min. ΔH_1. millims.	$t_1 = 2$ min. ΔH_2. millims.	$t_1 = 3$ min. ΔH_3. millims.
0	111·65	119·56	123·06
0	103·76	119·12	123·06
0	106·17	118·71	122·84
0	105·18	118·99	123·00
0	106·17	119·42	123·17
0	105·69	119·35	123·06
Mean . .	106·44	119·19	123·03

In another experiment, where $t_1 = 1$ min. throughout, ΔT was taken as 10°, 20°, and 30° C. in succession.

$$T = 20^{\circ}{\cdot}17$$
$$T_1 = 30{\cdot}17$$
$$T_2 = 40{\cdot}17$$
$$T_3 = 50{\cdot}17.$$

	$t_1 = 1$ min.		
t. s	ΔT=10°. millims.	ΔT=20°. millims.	ΔT=30°. millims.
0	106·17	235·47	414·48
0	105·86	233·83	422·49
0	106·17	234·29	421·24
Mean . .	ΔH=106·07	234·53	419·40

We can employ these correctionary data to the numbers subsequently obtained when liquids intervene, without previously reducing the linear depression to cubic proportional expansion.

§ 51. *Relation between resistance and thickness.*—We have already obtained some notion of this relation in examining the time t required for heat to traverse different thicknesses of water. Taking the same liquid, we may now estimate the resistance by finding how much heat passes through in a given time, and therefore how much is arrested. The resistance is considered as the number of heat-units (1 grm. 1° C.) which the liquid arrests in a given time; but for our present purpose we need not make the latter reduction; the corrected linear depression in millimetres will suffice.

$$T = 19^{\circ}{\cdot}28$$
$$T_1 = 29{\cdot}28$$
$$\Delta T = 10 \text{ C.}$$
$$t_1 = 1 \text{ min.}$$

δ.	Resistance mean of five experiments. millims.	ΔR millims.
2·5	63·00	
		3·09
3·0	66·09	
		5·65
3·5	71·74	
		8·42
4·0	80·16	
		5·88
4·5	86·04	
		6·93
5·0	92·97	
		2·25
5·5	95·22	
		4·56
6·0	99·78	
		3·04
6·5	102·82	

It is seen, on comparing the numbers of column ΔR millims., that there is a continual increase of resistance with the thickness, but it would not be safe from these numbers to attempt to deduce any law (see fig. 6).

§ 52. *Relation of resistance to time* t_1 *and temperature.*—In another series of experiments a set of brass cones were employed having brass bottoms. The depression when they were in contact was not measured. The interval δ can only be considered approximately as 2 millimetres, but it was perfectly constant throughout. For these reasons the numbers given can only be compared *inter se.* The necessary reductions are made for pressure. The depression produced by the passage of water of a certain temperature through the upper cone was allowed to attain a maximum, and then water of a known higher temperature was passed through. The water in the interstice was brought to a uniform temperature by stirring with a slender wooden splinter. The numbers are given in the units of the arbitrary scale (1 H=4·826 millims.).

$$H=37$$
$$T=13^\circ{\cdot}06$$
$$\Delta T=5^\circ{\cdot}55$$
$$\delta=2 \text{ millims. } \textit{circa.}$$

t_1.	$T_1-T=5^\circ{\cdot}55$. H_1.	$T_2-T_1=5^\circ{\cdot}55$. H_2.	$T_3-T_2=5^\circ{\cdot}55$. H_3.	$T_4-T_3=5^\circ{\cdot}55$. H_4.	$T_5-T_4=5^\circ{\cdot}55$. H_5.
1 min.	47	71	110	146	180
2	55	84·5	122	156	192
3	58	89·5	128	160	196
4	59	91·0	129·5	161	196
5	60·5	91·5	130·5	161	196
6	61	92·2	131		
7	61	92·5	131		
8	. . . .	92·5	131		
9	. . . .	92·5	131		
10	. . . .	92·6			

It appears from the above Table that warm water conducts more heat than cooler in the same time for the same temperature-difference. The temperature-difference being constant (5°55 C.) the corresponding expansions are in one minute

from $T=13^{\circ}{\cdot}06$	from $T_1=18^{\circ}{\cdot}61$	from $T_2=24^{\circ}{\cdot}16$	from $T_3=29^{\circ}{\cdot}71$	from $T_4=35^{\circ}{\cdot}26$
to $T_1=18{\cdot}61$	to $T_2=24{\cdot}16$	to $T_3=29{\cdot}71$	to $T_4=35{\cdot}26$	to $T_5=40{\cdot}81$
Expansion $=10$.	Expansion $=10$.	Expansion $=11{\cdot}4$.	Expansion $=15$.	Expansion $=19$.

We also conclude from the above deduced values, not only that the resistance diminishes with the temperature, but also that the diminution of resistance is greater for equal increments of temperature at higher than at lower temperatures.

§ 53. The first of these results, namely, that resistance diminishes with increase of temperature, agrees fully with the result given in §§ 43, 46, that the rate of penetration t is less for less temperature-differences than for greater ones. The cause of the more speedy penetration of great heats is in fact due to the less resistance offered to the passage of the heat by those portions of the liquid which have already been heated.

VII. *Influence of Constitution of the Liquid on the quantity of the Heat which passes.*

§ 54. In experimenting in the manner described in §§ 15, 16, M. Despretz concluded that the conductivities of fresh and salt water were virtually the same. The important cosmical bearing of this question induced me to examine it by means of the diathermometer, and at the same time to examine the relative conducting-powers or resistances of some other aqueous solutions. Preliminary experiments having shown that the resistances of such solutions were very nearly the same as that of water, I have preferred for the present the examination of saturated, or nearly saturated solutions to those which contain either equal or equivalent amounts of solid salt. The solutions of the pure salts were saturated at the atmospheric temperature, and a single drop of water was added to each to prevent crystallization during the experiment, which would of course vitiate the result. The results are given, as before, in corrected millimetres of depression; the numbers are in the proportion of the numbers of heat-units arrested (comp. § 50).

$$T=19^{\circ}{\cdot}72$$
$$\Delta T=20$$
$$\delta=2 \text{ millims.}$$
$$t_1=1 \text{ min.}$$

	millims.	millims.	millims.	Mean resistance. millims.
Distilled water	99·64	101·77	100·71	100·70
Chloride of sodium (nearly sat.)	101·11	101·72	101·47	101·43
Chloride of calcium (,, ,,)	105·68	104·43	104·96	105·02
Carbonate of potassium (,, ,,)	109·20	107·13	111·47	109·26

The two latter of these substances were chosen on account of their great solubility.

§ 55. Two aqueous solutions were now taken of salts whose metals in the elementary state have little resistance, namely, silver and copper. These were again compared with water.

$$T=20^{\circ}{\cdot}83$$
$$\Delta T=20$$
$$\delta=2 \text{ millims.}$$
$$t_1=1 \text{ min.}$$

	Water.	Nitrate of silver (nearly sat.).	Sulphate of copper (nearly sat.).
	millims.	millims.	millims.
Resistance (1)	98·64	106·64	104·22
,, (2)	99·60	104·23	105·72
Mean . . .	99·12	105·43	104·97

The difference between this value for water and the value given in § 54 may partly arise from the difference $(0^{\circ}{\cdot}8)$ of T, but is more probably due to a minute error in δ, as the cones had been separated between these two experiments. It is also seen that there are in one or two cases greater differences between the determinations of the same substance than between those of different substances. In order to get results of sufficient accuracy for the establishment of the law of resistance under these circumstances, a very much greater number of experiments must be performed with an instrument of greater sensibility. I hope to be able to lay such results on a future occasion before the Society.

§ 56. Meanwhile the following conclusions appear unavoidable, even from the above incomplete experiments. The solution of a metallic salt in water invariably increases the thermal resistance of the water. Those elements which dissolve in the water without increasing the bulk of the water, can only increase its thermal resistance by increasing its capacity for heat, which must in such cases be the sum of the capacities of the water and elements separately. The thermal resistance of a solid salt is greater than that of water, consequently when, as in the majority of instances, water is displaced by the salt, the increased resistance is due to the partial substitution of a body of greater resistance. This increase is partly counterbalanced by the inferior specific heat of the salt. The nature of the metallic base of the salt in regard to its thermal resistance in the free state has little influence upon the thermal resistance of the solution of the salt*.

§ 57. The difference in thermal resistance between fresh and salt water must be of very considerable importance in thalattology, but the consideration of this would be beyond the scope of my present purpose.

§ 58. A branch of the investigation of surpassing interest is the comparison of the resistances offered by liquids of entirely different chemical composition. In the experiments the results of which are given below, in order that the experiments might be as exact as possible, times were chosen at which the atmospheric temperature was the same; several weeks were thus employed. The cones were not moved during this time, so that even if there was a minute error in the value of δ ($\delta=1$ millim.) the results would be at all events comparable. The column of specific resistances is obtained by dividing the resistances of the other liquids by that of water, which of all transparent liquids appears to have by far the least thermal resistance.

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* I am inclined to think that it has none. Compare also § 70.

§ 59. With regard to the purity of the substances, they had in many cases been prepared for research by Mr. Chapman or Mr. Wanklyn (to whom I am indebted for specimens), with special view to their absolute purity. The glycerine was heated on a water-bath for a day, and kept *in vacuo* over sulphuric acid for several days. The acetone was prepared by myself from acetate of barium, and had been combined with sulphite of ammonium. The water was well boiled immediately before use. The sperm-oil was the ordinary commercial, which had been kept for several hours at 100° C. The alcohol was dried over carbonate of potassium, and twice distilled from quicklime. The nitrobenzol was simply dried and distilled; it might from its history contain a little nitrotoluol. The amylic alcohol when dried boiled at 132° C. The oil of turpentine was commercial, which had been rectified. The chloroform was also commercial; it was alternately shaken with strong sulphuric acid and sticks of potash. The remainder, acetic acid, oxalate of ethyl, acetate of ethyl, oxalate of amyl, butylic alcohol, acetate of amyl amylamine, nitrate of butyl, bichloride of carbon, mercury amyl, bromide of ethylen, iodide of amyl, iodide of ethyl, were all either analyzed or titrated by one of the above-named chemists or by myself, and were shown to be of exceptional purity. The final drying was, wherever possible, performed by means of anhydrous phosphoric acid.

§ 60. On account of their volatility some of these liquids might be supposed to give resistances too high. I was, indeed, unable to examine ether and bisulphide of carbon on this account. But those in the Table were seen to lose an inappreciably small quantity by vaporization, and to produce before being heated scarcely any elevation of the water in Q. For various reasons, it is probable that the number for iodide of ethyl is wrong, and that this liquid is misplaced. An idea of the amount of surface exposed may be got by imagining a tube 13·4 millims. long and 1 square millimetre section, closed at one end, filled with the liquid and exposing therefore at the open end 1 square millimetre.

$T = 20^\circ{\cdot}17$ C.
$T_1 = 30{\cdot}17$
$\Delta T = 10$
$\delta = 1$ millim.
$t_1 = 1$ min.

	Thermal resistance in millimetres.	Specific Thermal resistance.
Water	4·13	1·0
Glycerine	15·85	3·84
Acetic acid (glacial)	34·63	8·38

	Thermal resistance in millimetres. millims.	Specific Thermal resistance.
Acetone	35·14	8·51
Oxalate of ethyl	36·56	8·85
Sperm-oil	36·56	8·85
Alcohol	37·53	9·09
Acetate of ethyl	37·53	9·09
Nitrobenzol	40·81	9·86
Oxalate of amyl	41·29	10·00
Butylic alcohol	41·29	10·00
Acetate of amyl	41·29	10·00
Amylamine	41·88	10·14
Amylic alcohol	42·26	10·23
Oil of turpentine	48·53	11·75
Nitrate of butyl	49·01	11·87
Chloroform	49·98	12·10
Bichloride of carbon	53·35	12·92
Mercury amyl	53·35	12·92
Bromide of ethylen	54·34	13·16
Iodide of amyl	54·80	13·27
Iodide of ethyl	58·66 (?)	14·20 (?)

§ 61. A special determination was made with the strongest oil of vitriol, H_2SO_4, and with the same diluted with fourteen times its volume of water. The strong sulphuric acid showed a specific resistance of 1·33, and the dilute of 1 exactly.

§ 62. The results obtained from endeavours to connect mercury with the above series have given me the number 0·13 as the specific resistance of that metal. But there is so little difference between the depression produced when the cones are in contact, and that which occurs when 1 millim. of mercury interposes, that a slight error in observation would make a very great difference. I give this number for mercury therefore with very great reserve, and only to show that the resistance of water is many times greater than that of mercury.

§ 63. At the conclusion of one of his papers "On the Absorption of Heat by Liquids," Dr. TYNDALL uses the expression "bisulphide of carbon is the rock-salt of liquids." It appears from the Table (§ 60) that we may with equal propriety say that "water is the silver of liquids," at least of the non-metallic ones; for it shows as great a preeminence amongst liquids as silver does amongst metals.

§ 64. It appears that after water itself those liquids have least resistance which contain hydrogen easily replaceable by a metal, as acetic acid, sulphuric acid, and glycerine. This fact forcibly suggests the experiments of Herr MAGNUS on the conductivities of the gases, and the extraordinarily great conductivity of hydrogen. As, however, the conclusions drawn by Herr MAGNUS from his experiments have been questioned by Dr. TYNDALL and other physicists, I refrain from doing more than point out this distinct coincidence.

§ 65. Of bodies belonging to the same chemical series or isotypic bodies, those have the least thermal resistance which have the simplest constitution. Thus the resistances of the three alcohols examined are in the order amylic, butylic, and ethylic. Again, the acetate of amyl has greater thermal resistance than the acetate of ethyl, and the oxalate of amyl than the oxalate of ethyl. The only exception to this appears to be the iodide of ethyl in comparison with the iodide of amyl; but, as before stated, I am disposed to reject the determination of the former body.

§ 66. The only one of these liquids which contains a metal is mercury amyl, and this was tried under the expectation that, owing to the chemical construction of the body, the metallicity of the mercury in regard to its conductivity might appear. Contrary to anticipation, the liquid has one of the greatest resistances.

§ 67. Another noteworthy circumstance is the great specific resistance of all the liquids which contain halogens. May it be owing to the halogenous function of the mercury in the mercury amyl, which brings that liquid to so low a place?

The existence of these regularities and consistencies supports, at all events, the approximate and relative accuracy of the determinations, and by furnishing a new equation of physical property, opens a wide field for future research.

§ 68. If the results just given concerning thermal resistance be compared with those of Signor MELLONI and Dr. TYNDALL with regard to diathermancy, and especially with those of the latter philosopher concerning the absorption of radiant heat by various liquids, a striking dissimilarity at once appears. Taking the four liquids common to both, water, alcohol, acetate of ethyl, and chloroform, Dr. TYNDALL found that of 100 heat-rays of an Argand burner they absorbed—

Water (saturated with Na Cl)	86·1
Alcohol	78·6
Acetate of ethyl	74·0
Chloroform	25·0

respectively when the thickness was 0·04 inch (1 millim.$=$0·03937 inch). These liquids are accordingly in exactly the inverse order to that in which they appear in the Table, § 60*. That this apparent contradiction is in fact a coincidence appears from the following considerations.

§ 69. The diathermancy of a liquid towards radiant heat, and its resistance to contact heat, are partly due to one and the same cause. The amount of absorption of radiant heat by a liquid, as determined by Dr. TYNDALL, is estimated by the quantity of heat which passes through the body so as to affect the thermomultiplier; and the amount of absorption is directly proportional to the athermancy. Now a liquid which absorbs heat well, and is consequently highly athermanous, forms on that very account an abundant source of heat to bodies in contact with it. And if the heat move through the liquid, by way of conduction, with facility, the quantity of heat which the heated liquid gives up in a given time to another body in contact with it, is great—that is, the resistance of the liquid is found to be small.

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* To my great regret I have not yet been able to determine the resistance of bisulphide of carbon; but I scarcely hesitate to predict that it has a very great, perhaps the greatest thermal resistance.

§ 70. Though more or less heat passes instantly through a partly athermanous liquid, yet some is absorbed, and the amount absorbed, and therefore the degree of athermancy, is not independent of the specific heat of the liquid; for the transmitted heat is measured before the liquid has become a secondary source of radiant heat in virtue of the heat which it has arrested. It is found, indeed, that the order of absorption in the case of water, alcohol, and bisulphide of carbon is the same as that of the specific heats of the same liquids.

§ 71. With contact heat the case is different; for when a liquid has a high specific heat, although the rise of temperature will be small when the heat enters it, yet this small increment of temperature corresponds to a large absolute accession of heat; so that when, as in my experiments, the liquid becomes a source of heat the absolute quantity of heat given out is also great; hence the specific heat of the liquid in these contact experiments is of no influence. Accordingly we need not look to the different nature of the heat employed to reconcile my experiments with those of Dr. TYNDALL.

§ 72. Concerning the relation between thermal and electrical resistances, a few remarks may be allowed. It has been shown in §§ 46 *seq.*, §§ 52 *seq.*, that the hotter a liquid (water) is, the less is its resistance, both as measured by the time t required for the first penetration, and by the quantity of heat arrested in a given time-lapse. This is in accordance with the observations of WIEDEMANN, who found that the resistance of a solution of sulphate of copper diminished more than one half when its temperature was raised 55° C., and with the general law of liquids that the resistance diminishes as the temperature increases. With metals, as has been long known, the electrical resistance increases with the temperature. If, therefore, in the case of electricity the law connecting resistance with temperature is the reverse with liquids to what it is with solids, it may well be so with heat; so that while hot solids may conduct heat worse than cold ones, a hotter liquid may conduct heat better than a colder one.

§ 73. The experiments § 61 were especially made to determine whether the addition of sulphuric acid, which so greatly diminishes the electrical resistance of water, has a similar effect upon its thermal resistance. As with electricity so with heat, we find that strong sulphuric acid has greater resistance than dilute. But in the case of heat we do not find that enormous difference in resistance between water and dilute sulphuric acid which is found with electricity. Nor are we justified in expecting it; for in the case of the electrical resistance of a mixture or compound of electrolytes the magnitude of the effect is measured ultimately by the degree of induced polarity; in the case of thermal resistance, it appears to depend arithmetically upon the quantities and respective resistances of the constituents.

§ 74. In order to calculate the number of heat-units arrested by a mass of liquid of given thickness and surface, we must proceed as follows. Take, for example, the depression-difference for water, § 60, namely, 4·13 millims. This has, like all the other values of the resistances, been corrected for the calibre of the tube and for the variation in pressure. It is found from the Tables that

4·13 millims. is equivalent to 0·02829 cub. centims.,

or

45 cub. centims. have become 45·02829 cub. centims.;

hence from

$$x^\circ \times 45 \times 0{\cdot}00366 = 0{\cdot}02829$$

we find

$$x^\circ = 0{\cdot}17177,$$

that is, an amount of heat has been arrested which would heat

45 cub. centims. of air through 0°·17177 C.,

or

1 cub. centim. of air through 7°·72965 C.,

or

1 cub. centim. of water through $7{\cdot}72965 \times 0{\cdot}237 \times 0{\cdot}001296$,

where 0·237 is the specific heat of air for constant pressure, and 0·001296 is the specific gravity of air (both referred to water). Consequently the heat arrested would heat 1 cub. centim. of water through 0°·0023732 C. This number, therefore, expresses the number of heat-units arrested in 1 minute by a circular disk of water 53·34 millims. in diameter and 1 millim. in thickness. Hence the number of heat-units arrested in 1 minute by a layer of water 1 millim. thick and 1 square decimetre of surface is

0·0106.

Calling U_r the number of heat-units resisted, we thus find:—

	Number of heat-units arrested in 1 minute by 1 square decimetre, 1 millim. in thickness when T=20°·17 C. and ΔT=10° C. U_r.
Water	0·0106
Glycerine	0·0407
Acetic acid	0·0888
Acetone	0·0902
Oxalate of ethyl	0·0938
Sperm-oil	0·0938
Alcohol	0·0963
Acetate of ethyl	0·0963
Nitrobenzol	0·1045
Oxalate of amyl	0·1060
Butylic alcohol	0·1060

	Number of heat-units arrested in 1 minute by 1 square decimetre, 1 millim. in thickness when $T=20^\circ{\cdot}17$ C. and $\Delta T=10^\circ$ C. U_r.
Acetate of amyl	0·1060
Amylamine	0·1075
Amylic alcohol	0·1084
Oil of turpentine	0·1245
Nitrate of butyl	0·1258
Chloroform	0·1283
Bichloride of carbon	0·1369
Mercury amyl	0·1369
Bromide of ethylen	0·1395
Iodide of amyl	0·1407
Iodide of ethyl	0·1505

In submitting these results to the Royal Society I am fully conscious of their incompleteness. I hope shortly to be able to extend my experiments, and to increase their accuracy. Meanwhile I would invite physicists to this interesting and important field of research, which promises an abundant yield to many independent cultivators.

My thanks are due to the Managers and Professors of the London Institution for affording me an opportunity of carrying out my experiments.

Fig. 2.

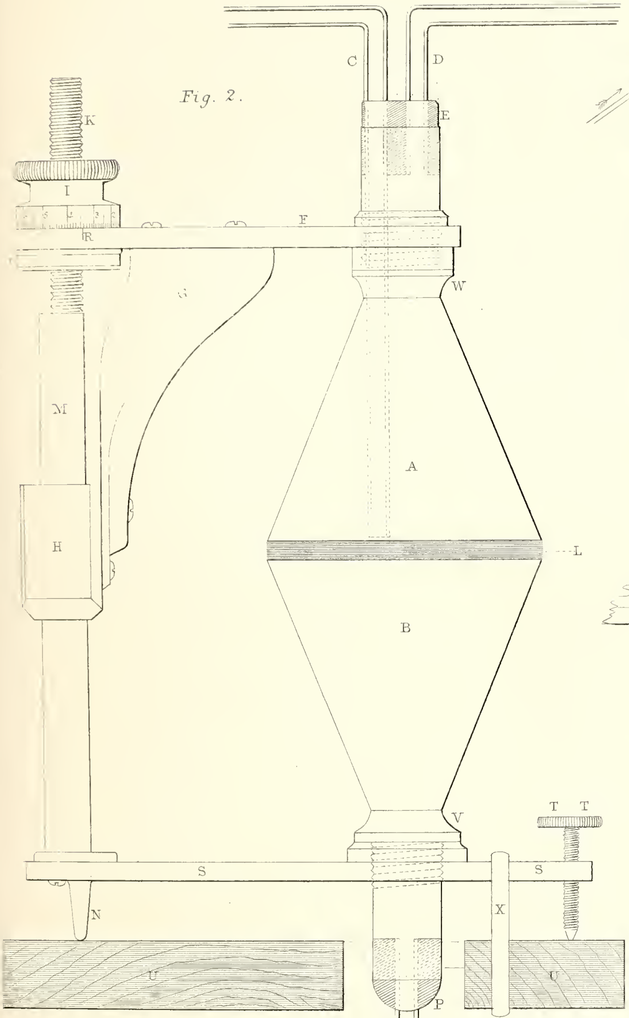


Fig. 3.

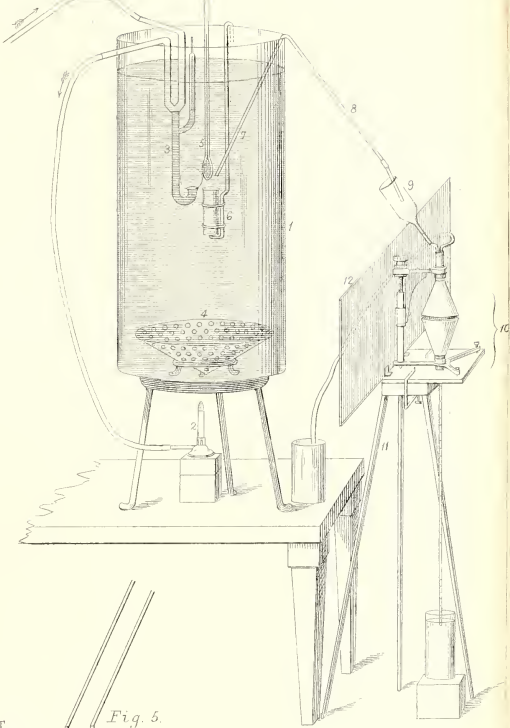


Fig. 5.

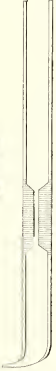


Fig. 6.

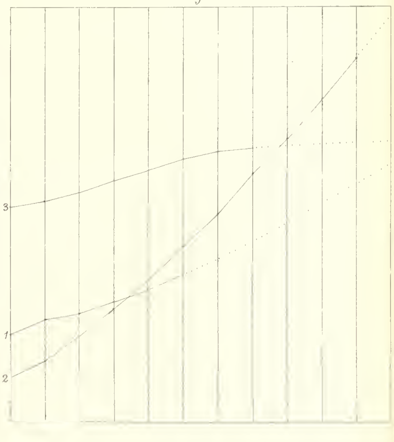


Fig. 1.

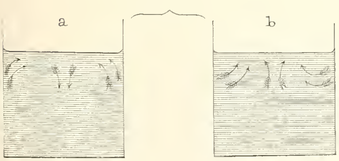
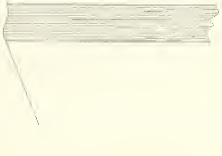


Fig. 4.



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BRITISH MUSEUM NATURAL HISTORY.

XXIII. *Researches into the Chemical Constitution of Narcotine, and of its Products of Decomposition.*—Part III. *By* Augustus Matthiessen, *F.R.S.*, *Lecturer on Chemistry in St. Bartholomew's Hospital.*

Received February 18,—Read March 18, 1869.

In Part II. of this investigation, carried out in conjunction with Professor Foster, it was stated that when narcotine is heated for some time with strong hydrochloric acid a new base was formed, which we called methyl-normal-narcotine, or methyl-nornarcotine, being derived from narcotine by replacing two atoms of methyl by two of hydrogen.

In continuing the research into this subject, it has been observed that when narcotine is heated with hydrochloric acid, for only a short time, one atom of methyl is replaced by hydrogen; and further, that when narcotine is heated with fuming hydriodic acid, three atoms of methyl are replaced by three of hydrogen, thus forming two other bases, the description of the preparation and properties of which form the subject of this Memoir.

1. *On the Action of Hydriodic Acid on Narcotine.*

When narcotine is heated with fuming hydriodic acid, iodide of methyl is evolved, and on investigating the residue it was found to consist of the iodide of a new base. To prepare this the following method was emyloyed: fuming hydriodic acid (made by converting iodine into hydriodic acid by sulphuretted hydrogen, evaporating the solution, and, when cold, saturating it with gaseous hydriodic acid) is made to act on narcotine in a retort at the boiling-point of the mixture, when iodide of methyl is immediately given off and a tarry mass left in the retort, which is chiefly the iodide of the new base.

In two experiments made with 50 grms. of narcotine, 45·7 and 46·2 grms. of iodide of methyl, and in a third experiment with 100 grms. of narcotine, 91·8 grms. of iodide of methyl, were obtained, 51·5 grms. and 103·1 grms. being the theoretical quantities required for the following reaction:—

$$C_{22}H_{23}NO_7 + 3HI = C_{19}H_{17}NO_7 + 3CH_3I.$$

If the reaction

$$C_{22}H_{23}NO_7 + 2HI = C_{20}H_{19}NO_7 + 2CH_3I$$

took place, the theoretical quantity of iodide would only be 34·3 grms. and 68·7 respectively.

All endeavours to obtain the base in a state fit for analysis have been fruitless, owing to its rapidly oxidizing when exposed to the air; to establish its composition the following method was adopted. After distilling off the iodide of methyl, the contents of the retort were thrown into water, the free acid neutralized by carbonate of sodium, and then water added till all the iodide was dissolved. The iodide is much more soluble in a neutral solution than in an acid one. To the solution of the iodide hydrochloric acid is added until no further precipitate takes place; this precipitate consists chiefly of the chloride of the new base. The chloride is filtered off and redissolved in water (for it behaves like the chloride of methyl-nornarcotine, being far more soluble in pure than in acidulated water), and reprecipitated with hydrochloric acid. This operation is repeated until the precipitate contains no longer any iodine.

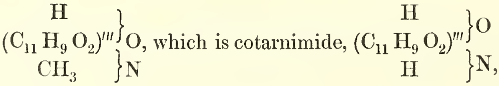
The analysis of this chloride, dried first over lime and sulphuric acid, and then in the water-bath, gave the following results. The substance was burnt with chromate of lead and oxygen. The chlorine determinations were made in the usual manner.

I. 0·5073 grm. substance gave 1·0387 grm. carbonic acid and 0·2108 water.
II. 0·4790 grm. substance gave 0·9830 grm. carbonic acid and 0·2050 water.
III. 2·066 grms. substance gave 0·7332 grm. chloride of silver.
IV. 1·595 grm. substance gave 0·5506 grm. chloride of silver.

	Calculated.		Found.			
			I.	II.	III.	IV.
C_{19}	228	55·95	55·79	55·95	——	——
H_{18}	18	4·42	4·62	4·76	——	——
N	14	3·44	——	——	——	——
O_7	112	27·48	——	——	——	——
Cl	35·5	8·71	——	——	8·77	8·54
$C_{19}H_{17}NO_7HCl$	407·5	100·00				

The analyses I. and III. and II. and IV. were made from samples prepared at different times, and the portions employed for the above determinations were obtained by fractional precipitation. The chloride when first precipitated is almost white, but soon becomes slightly yellow. It is amorphous. The base itself, when newly precipitated, is nearly white, but as soon as it is exposed to the air it becomes almost black; it is soluble in carbonate of sodium and caustic soda, potash or ammonia, slightly soluble in hot alcohol, quite insoluble in ether, and nearly so in water. All endeavours to obtain it or its salts in a crystalline state have hitherto failed.

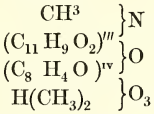
The base may be called normal narcotine, or, shorter, nornarcotine, as it contains, in all probability, normal meconin combined with cotarnimide. Thus in Part I. page 366 of this Memoir, carried out in conjunction with Professor FOSTER (Philosophical Transactions, 1863), it is stated that cotarnine may be written



$$\left.\begin{array}{l}H\\(C_{11}H_9O_2)'''\end{array}\right\}O,\ \left.\begin{array}{l}\\CH_3\end{array}\right\}N \quad \text{which is cotarnimide,} \quad \left.\begin{array}{l}H\\(C_{11}H_9O_2)'''\end{array}\right\}O\ \left.\begin{array}{l}\\H\end{array}\right\}N,$$

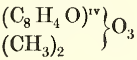
in which one atom of hydrogen is replaced by one of methyl; and in the Journal of the Chemical Society we suggest that the rational formulæ of narcotine may be written thus:

Narcotine.



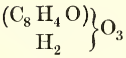
$$\begin{array}{ll} \left.\begin{array}{l}CH^3\end{array}\right\} & N \\ \left.\begin{array}{l}(C_{11}H_9O_2)'''\\(C_8\ H_4O\ )^{iv}\end{array}\right\} & O \\ \left.\begin{array}{l}H(CH_3)_2\end{array}\right\} & O_3 \end{array}$$

Meconine.



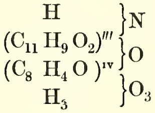
$$\left.\begin{array}{l}(C_8H_4O)^{iv}\\(CH_3)_2\end{array}\right\}O_3$$

Meconine being the dimethylized compound of the normal meconine,



$$\left.\begin{array}{l}(C_8H_4O)\\H_2\end{array}\right\}O_3$$

If the foregoing assumption as to the rational formula of narcotine is correct, that of the base now under consideration will be



$$\begin{array}{ll} \left.\begin{array}{l}H\end{array}\right\} & N \\ \left.\begin{array}{l}(C_{11}H_9O_2)'''\\(C_8\ H_4O\ )^{iv}\end{array}\right\} & O \\ \left.\begin{array}{l}H_3\end{array}\right\} & O_3 \end{array}$$

2. *On the Action of Hydrochloric Acid on Narcotine.*

When narcotine is heated with hydrochloric acid for about two hours, chloride of methyl is evolved, and on examining the residue it will be found to contain the chloride of a new base.

The best method of its preparation is as follows:—Narcotine (say 100 grms.) is placed in a large flask with a quantity of strong hydrochloric acid (500 cub. centims.) with a little paraffin, and heated on a water-bath for the space of three to four hours; much chloride of methyl is given off, and there remains behind in the retort the chloride of a new base. The reaction which takes place is simply that one atom of methyl in the narcotine is replaced by one of hydrogen, thus:

$$C_{22}H_{23}NO_7+HCl=C_{21}H_{21}NO_7+CH_3Cl.$$

To obtain the base from the chloride, the following process was adopted: as soon as the contents of the flask are cold they are neutralized by carbonate of sodium; this salt is then added in excess, which dissolves any methyl-nornarcotine, or nornarcotine which may have been formed during the reaction, and leaves the new base and any undecomposed narcotine. This may be separated by caustic potash, in which the new base is readily soluble, narcotine being insoluble in that reagent. The potash solution is acidulated with hydrochloric acid, and the base precipitated fractionally by carbonate of sodium.

The solution in which the base is suspended may be heated to 50° C. (but not higher, otherwise the base is apt to get sticky), when it filters readily.

The separation from narcotine may also be accomplished by alcohol, in which the new base is easily soluble. On analyzing the base the following results were obtained. It was dried in a Leibig's tube, first at 50° C., and then at 100° C.

I. 0·3600 grm. substance gave 0·8262 grm. carbonic acid and 0·1766 water.
II. 0·3500 grm. substance gave 0·8072 grm. carbonic acid and 0·1642 water.
III. 0·3820 grm. substance gave 0·8810 grm. carbonic acid and 0·1830 water.
IV. 1·0380 grm. substance gave 0·2680 grm. platinum.

	Calculated.		Found.			
			I.	II.	III.	IV.
C_{21} . . .	252	63·16	62·58	62·90	62·89	——
H_{21} . . .	21	5·26	5·45	5·21	5·32	——
N . . .	14	3·51	——	——	——	3·66
O_7 . . .	112	28·07	——	——	——	——
$C_{21}H_{21}NO_7$		100·00				

The pure base forms a white amorphous powder, almost insoluble in water and ether, very soluble in alcohol. Its salts, like those of other bases derived from narcotine, are, as far as they have been prepared, amorphous. The base may be called dimethyl-normal-narcotine, or, shorter, dimethyl-nornarcotine. The rational formula of this base is either

$$\begin{array}{ll} H & \\ & \}N \\ (C_{11}H_9O_2)''' & \\ & \}O \\ (C_8\ H_4O)^{\text{IV}} & \\ & \}O_3 \\ (CH_3)_2H & \end{array} \quad \text{or} \quad \begin{array}{ll} CH_3 & \\ & \}N \\ (C_{11}H_9O)''' & \\ & \}O \\ (C_8\ H_4O)^{\text{IV}} & \\ & \}O_3 \\ CH_3H_2 & \end{array}$$

if narcotine be

$$\begin{array}{ll} CH_3 & \\ & \}N \\ (C_{11}H_9O_2)''' & \\ & \}O \\ (C_8\ H_4O)^{\text{IV}} & \\ & \}O_3. \\ (CH_3)_2H & \end{array}$$

Further experiments will show which is the correct one: in the annexed Table the properties and reactions of the narcotine bases are given side by side. Neither of the above bases have any marked physiological effects; for in working with them, as well as in taking grain-doses, no ill effects have been observed. It is worthy of notice that the taste of the chlorides varies so markedly by the replacement of one atom of methyl by one of hydrogen.

	Form.	Solubility in			Solution of Chloride.	Taste of Chloride.	Reactions of the Chlorides in solution with			
		Water.	Alcohol.	Ether.			$PtCl_4$*.	KHO.	NH_4HO.	Na_2CO_3.
Trimethyl-normal-narcotine (ordinary narcotine), $C_{22}H_{23}NO_7$.	Crystalline.	Almost insoluble.	Soluble.	Soluble.	Not precipitated by HCl. Solution in HCl not precipitated by water.	Bitter.	Yellow precipitate.	Precipitate insoluble in excess.	Precipitate insoluble in excess.	Precipitate insoluble in excess.
Dimethyl-normal-narcotine, $C_{21}H_{21}NO_7$.	White amorphous.	Almost insoluble.	Very soluble.	Slightly soluble.	Precipitated partially by HCl. Solution in strong HCl precipitated by water; the precipitated chloride tarry.	Bitter.	Yellow precipitate.	Precipitate soluble in excess.	Precipitate slightly soluble in excess.	Precipitate soluble in excess.
Methyl-normal-narcotine, $N_{20}H_{19}NO_7$.	White when freshly precipitated, sometimes brown; amorphous.	Almost insoluble.	Insoluble.	Insoluble.	Mostly precipitated by HCl. Solution in strong HCl precipitated by water; precipitated chloride granular.	Astringent.	Yellow precipitate, slowly turning brown.	Precipitate soluble in excess.	Precipitate soluble in excess.	Precipitate soluble in excess.
Normal narcotine, $C_{19}H_{17}NO_7$.	White when freshly precipitated, turns brown immediately on exposure to air; amorphous.	Almost insoluble.	Insoluble.	Insoluble.	Almost wholly precipitated by HCl. Solution in strong HCl precipitated by water; the precipitated chloride granular.	Tasteless.	Yellow precipitate, immediately turning brown.	Precipitate soluble in excess.	Precipitate soluble in excess.	Precipitate insoluble in excess.
Cotarnine, $C_{12}H_{13}NO_3$.	White, generally buff colour, crystalline.	Almost insoluble.	Very soluble.	Very soluble.	Not precipitated by HCl. Solution in HCl not precipitated by water.	Bitter.	Yellow precipitate.	Precipitate slightly soluble in excess.	Precipitate soluble in excess.	Precipitate soluble in excess.

* All these precipitates decompose on boiling with excess of platinum chloride.

XXIV. *Researches into the Chemical Constitution of Narcotine, and of its Products of Decomposition.*—Part IV.

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It has been shown that when narcotine is treated with hydrochloric and hydriodic acids, chloride or iodide of methyl and a series of new bases are formed homologous with narcotine, each containing CH_2 less than the preceding one; thus:

Ordinary narcotine or trimethyl-nornarcotine . .	$C_{19}H_{14}(CH_3)_3NO_7$
Dimethyl-nornarcotine	$C_{19}H_{15}(CH_3)_2NO_7$
Monomethyl-nornarcotine	$C_{19}H_{16}(CH_3)NO_7$
Nornarcotine	$C_{19}H_{17}NO_7$.

In order to gain further insight into the constitution of these bases, endeavours were made to study their decompositions under the influence of reagents known to act upon narcotine; the unsatisfactory nature of the results thus obtained led to the trial of new reactions, the effects of which were first studied upon ordinary narcotine.

In the majority of cases the results were, however, extremely unsatisfactory, owing to the tendency of these bases to yield either tarry or humus-like uncrystallizable products.

When ordinary narcotine is treated with oxidizing agents such as binoxide of manganese and sulphuric acid, or bichromate of potassium and sulphuric acid, nitric acid, or platinic chloride, it takes up an atom of oxygen and splits up into opianic acid and cotarnine; it was hoped that under similar circumstances the new bases would undergo analogous decompositions, yielding bodies homologous with these two products; in nearly every case, however, for the reasons above stated, the bodies produced could not be isolated in sufficient quantity and purity for examination and analysis. Before stating the results of the few experiments, which are of a positive character, it may be as well to mention those obtained with ordinary narcotine.

§ I. *Decompositions of Ordinary Narcotine.*

1. *Action of Water.*—When narcotine is submitted to the action of water, either by boiling in open vessels or by heating to above 100° C. in sealed tubes, it splits up into meconin and cotarnine,

$$C_{22}H_{23}NO_7 = C_{10}H_{10}O_4 + C_{12}H_{13}NO_3.$$

This reaction takes place much more readily under the latter circumstances. Owing to the ease with which cotarnine itself is thus decomposed, it is somewhat difficult to obtain it in a sufficiently pure state for analysis; hence, when this is the object in view, the reaction must be stopped long before the whole of the narcotine has been decomposed; meconin, on the contrary, undergoes no change under these circumstances. As has been previously observed, when crystallized narcotine is heated in sealed tubes together with water, it gradually disappears, yielding a slightly coloured solution; on repeating this experiment, an oily liquid sinking to the bottom of the tube was formed, and on continuing the heat, this gradually disappeared. This liquid, when examined, appeared to be simply a solution of unaltered narcotine in the melted meconin: no permanent gas was formed when the temperature did not rise above 160° C., but the smell of methylamine was always perceptible, and the more so the longer the time of heating; this was found to be due to the partial decomposition of the cotarnine. On opening a tube where all the narcotine had disappeared, the yellow liquid was found to be strongly alkaline, and on being acidified with hydrochloric acid, deposited crystals of meconin on cooling after evaporation.

The meconin from a series of tubes, when purified by successive recrystallizations, presented all the physical characters of ordinary meconin, viz. melting under boiling water, solubility in hot water, alcohol, and ether, and comparative insolubility in cold water and dilute acids and alkalies, and yielded the following results on analysis, after complete desiccation at 100°:—

0·4085* grm. gave 0·9180 carbonic acid and 0·1900 water.

	Calculated.		Found.
C_{10}	120	61·85	61·29
H_{10}	10	5·15	5·16
O_4	64	33·00	——
$C_{10}H_{10}O_4$ . .	194	100·00	

To obtain the cotarnine, the acidulated liquors from which the meconin had been obtained by crystallization, or extraction with ether, were supersaturated with ammonia, which threw down the unaltered narcotine and tarry matter, and acetate of lead was added; the filtrate from the dense precipitate of hydrated oxide and tarry matters thus produced was concentrated by evaporation over sulphuric acid after addition of a considerable quantity of caustic potash; cotarnine was thus gradually precipitated, and was purified by solution in hydrochloric acid and reprecipitation by excess of caustic potash; after washing until the filtrate was no longer alkaline, it was converted into platinum-salt, well washed with alcohol and ether, and dried over sulphuric acid.

0·4210 grm. of this salt, ignited, left 0·0965 grm. of platinum.

	Calculated.		Found.
	Narcotine $(C_{22}H_{23}NO_7)_2$ 2HCl, PtCl$_4$.	Cotarnine $(C_{12}H_{13}NO_3)_2$ 2HCl, PtCl$_4$.	
Platinum per cent. . . .	16·0	23·2	22·9

Owing to its easy decomposition, the quantity of cotarnine found was much less than the amount of meconin simultaneously produced; the products of its decomposition could not be isolated.

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* All combustions given in this paper were made with oxide of copper and oxygen.

Narcotine boiled *per ascensum* with water for fourteen hours did not perceptibly alter in bulk or appearance; the aqueous liquor on concentration deposited crystals of meconin, recognized by their physical characters.

This splitting up of narcotine under the influence of heated water may explain the occurrence of meconin in opium and opium-residues, as probably the small amount of meconin always found is simply due to the partial decomposition of the narcotine during the processes of extraction of morphia.

As narcotine is considerably more soluble in alcohol than in water, it was thought that the decomposition in sealed tubes with the former reagent might take place more readily than with the latter; in two comparative experiments, however, the reaction was found to occur more readily with water than with weak alcohol.

The addition of a small amount of caustic potash to the water used in the sealed-tube experiments did not appreciably modify the result, saving that rather more methylamine was produced.

Boiling with dilute potash even for twenty hours was not found to produce any meconin (or opianic acid); the potash liquor, however, was found to have dissolved a considerable quantity of unaltered narcotine; under ordinary circumstances narcotine is almost absolutely insoluble in potash solution.

2. *Action of Heat.*—As formerly observed, when narcotine is heated to temperatures short of 180°, no action is perceptible beyond a slight yellowish coloration; at about 210° it swells up, emitting a fragrant odour and combustible gases, and leaving a pasty carbonaceous mass.

A portion of narcotine was cautiously heated to 205°–208°, and the heat withdrawn when the decomposition was just commencing; on extracting the mass with hot water, a liquor was obtained from which meconin crystallized out on cooling, identified by its peculiar physical characteristics; the other products of decomposition could not be isolated.

3. *Action of Ferric Chloride.*—When hydrochlorate of narcotine is heated with a moderately concentrated solution of ferric chloride, the latter is reduced and a considerable quantitity of opianic acid formed: to convert the whole of the narcotine employed, several days' successive ebullition is necessary, the opianic acid obtained being thus approximately equal to the theoretical amount; thus in two experiments the opianic acid obtained (partly by crystallization, partly by extraction with ether) amounted to 48 and 47 per cent. of the narcotine employed, the theoretical yield being 50·8 per cent.

This acid possessed all the properties of opianic acid. After purification by successive recrystallizations, it gave the following numbers on analysis:—

I. 0·4410 grm., dried at 100°, gave 0·9170 carbonic acid and 0·1860 grm. water.

II. 0·3750 grm. gave 0·7890 carbonic acid and 0·1590 water.

	Calculated.		Found.	
			I.	II.
C_{10}	120	57·14	56·71	57·37
H_{10}	10	4·76	4·69	4·71
O_5	80	38·10	——	——
$C_{10}H_{10}O_5$	210	100·00		

Cotarnine is produced at the same time, but is quickly decomposed by the action of the ferric chloride; a small amount of the platinum-salt of this base was obtained from the iron liquors by the ordinary process for obtaining cotarnine; of this, dried over sulphuric acid, 0·6130 grm. left 0·1340 platinum.

	Calculated.		Found.
	Narcotine.	Cotarnine.	
Platinum per cent. . . .	16·0	23·2	21·9

Hence the salt was probably mixed with a small quantity of the narcotine platinum-salt from undecomposed narcotine.

§ II. *Decomposition of the Narcotine Bases.*

1. *Dimethyl-Nornarcotine.*—As narcotine under the influence of heat and water has been shown to split up into meconin and cotarnine, it appears probable that this base under the same circumstances would split, either into methyl-normeconin and cotarnine, or into ordinary meconin and a body containing CH_2 less than cotarnine (*i. e.* cotarnimide).

$$\overset{\text{Narcotine.}}{C_{19}H_{14}(CH_3)_3NO_7} = \overset{\text{Meconin.}}{C_8H_4(CH_3)_2O_4} + \overset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3}$$

$$\left\{\begin{array}{l} \overset{\text{Dimethyl-nornarcotine.}}{C_{19}H_{15}(CH_3)_2NO_7} = \overset{\text{Methyl-normeconin.}}{C_8H_5(CH_3)O_4} + \overset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3} \\ C_{19}H_{15}(CH_3)_2NO_7 = \overset{\text{Meconin.}}{C_8H_4(CH_3)_2O_4} + \overset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3} \end{array}\right.$$

On heating the base with water in sealed tubes, there were produced small quantities of a body having the characteristic property of methyl-normeconin and methyl-noropianic acid, viz. of yielding a blue colour with ferric salts, becoming light red with ammonia; but however the conditions of the experiment were varied, the yield of this substance was too small (even from moderately large quantities of base) for analysis and investigation.

The action of certain oxidizing agents also tends to prove that the former of the two last reactions takes place. The action of ferric chloride on narcotine has been shown to be

$$\overset{\text{Narcotine.}}{C_{19}H_{14}(CH_3)_3NO_7} + O = \overset{\text{Opianic acid.}}{C_8H_4(CH_3)_2O_5} + \overset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3}.$$

(Blyth has also obtained the same reaction with platinic chloride.) Hydrochlorate of dimethyl-nornarcotine, boiled with either ferric or platinic chloride for many hours, gives rise to the production of methyl-noropianic acid and cotarnine, not of opianic acid and cotarnimide.

$$\underset{\text{Dimethyl-nornarcotine.}}{C_{19}H_{15}(CH_3)_2NO_7} + O = \underset{\text{Methyl-noropianic acid.}}{C_8H_5(CH_3)O_5} + \underset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3},$$

and not

$$C_{19}H_{15}(CH_3)_2NO_7 + O = \underset{\text{Opianic acid.}}{C_8H_4(CH_3)_2O_5} + \underset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3}.$$

The yield of methyl-noropianic acid by either process is much less than the theoretical amount, probably from a secondary decomposition; it may be obtained from the iron or platinum liquors by simple extraction with ether and purification by recrystallization from water; if undecomposed narcotine is present in the base, opianic acid is likewise produced, and the two may be separated by fractional crystallization, the latter being much less soluble in cold water than the methyl-noropianic acid. A portion thus purified presented the physical characters of methyl-noropianic acid obtained by the action of hydrochloric on opianic acid, and gave the same reactions with ferric solutions: it contained no water of crystallization, and after drying at 100°, yielded the following numbers on analysis:—

I. was made with a specimen prepared by the action of ferric chloride; II. and III. by platinic chloride.

I. 0·2200 grm. gave 0·4440 carbonic acid and 0·0870 water.
II. 0·3130 grm. gave 0·6330 carbonic acid and 0·1250 water.
III. 0·3050 grm. gave 0·6180 carbonic acid and 0·1200 water.

	Calculated.		Found.		
			I.	II.	III.
C_9	108	55·10	55·04	55·14	55·26
H_8	8	4·08	4·39	4·43	4·37
O_5	80	40·82	——	——	——
$C_9H_8O_5$ . .	196	100·00			

All attempts to procure the cotarnine formed in sufficient quantity and purity for analysis were fruitless.

No other means of oxidation or decomposition tried were successful; the above reactions, however, tend to show that dimethyl-nornarcotine is derived from narcotine by the substitution of H for CH_3 in the meconin radical, and not in the cotarnine, its rational formula being as follows, that of narcotine being*

$$\begin{array}{cc} \text{Narcotine.} & \text{Dimethyl-nornarcotine.} \\ \begin{array}{l} \left.CH_3\right\}N \\ \left.\begin{array}{l}(C_{11}H_9O_2)''' \\ (C_8\ H_4O)^{iv}\end{array}\right\}O \\ \left.(CH_3)_2H\right\}O_3 \end{array} & \begin{array}{l} \left.CH_3\right\}N \\ \left.\begin{array}{l}(C_{11}H_9O_2) \\ (C_8\ H_4O)\end{array}\right\}O \\ \left.(CH_3)H_2\right\}O_3. \end{array} \end{array}$$

---

* Journal of the Chemical Society.

2. *Monomethyl-nornarcotine.*—Just as dimethyl-nornarcotine might be narcotine, where H replaces CH_3 either in the meconine radical or in the cotarnine radical, so monomethyl-narcotine may be narcotine, where H_2 replaces $(CH_3)_2$ in the meconic radical, or where H replaces CH_3 in the cotarnine radical as well as in the meconin radical.

Hence either of the two following reactions with heated water might be anticipated —

$$\underset{\text{Monomethyl-nornarcotine.}}{C_{19}H_{16}(CH_3)NO_7} = \underset{\text{Normeconin.}}{C_8H_6O_4} + \underset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3},$$

or

$$C_{19}H_{16}(CH_3)NO_7 = \underset{\text{Methyl-normeconin.}}{C_8H_5(CH_3)O_4} + \underset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3}.$$

On trying the experiment it was found impossible to obtain anything but tarry masses: the fact that methyl-normeconin was not obtained would tend to show that the former reaction takes place, the normeconin immediately becoming decomposed; the cotarnine, however, could not be got sufficiently free from tar for analysis.

Similarly, with oxidizing agents either of the following reactions appears probable:—

$$\underset{\text{Monomethyl-nornarcotine.}}{C_{19}H_{16}(CH_3)NO_7} + O = \underset{\text{Noropianic acid.}}{C_8H_6O_5} + \underset{\text{Cotarnine.}}{C_{11}H_{10}(CH_3)NO_3},$$

or

$$C_{19}H_{16}(CH_3)NO_7 + O = \underset{\text{Methyl-noropianic acid.}}{C_8H_5(CH_3)O_5} + \underset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3}.$$

The non-oxidizing agents, and ferric chloride, only gave rise to the formation of tarry masses; but on boiling platinic chloride with hydrochlorate of monomethyl-nornarcotine, and extracting the liquor with ether, there was obtained a body which it was found impossible to obtain in a state of sufficient purity for analysis owing to its instability; it had an acid reaction, was very soluble in water, ether, and alcohol, but could be obtainable only as a tarry granular mass from any of these solvents; it gave only a very slight purplish coloration with ferric salts. Since its reactions, therefore, did not all correspond with those of methyl-noropianic acid, it appears probable that it was the noropianic acid formed according to the first of these two equations.

These results point to the constitution of methyl-nornarcotine as being narcotine, where H_2 replace $(CH_3)_2$ in the meconin radical; or, as before,

$$\begin{array}{ll} \text{Narcotine.} & \\ CH_3 & \Big\}N \\ (C_{11}H_9O_2)'' & \Big\}O \\ (C_8H_4O)^{\text{iv}} & \\ (CH_3)_2H & \Big\}O_3 \end{array} \qquad \begin{array}{ll} \text{Methyl-nornarcotine.} & \\ CH_3 & \Big\}N \\ (C_{11}H_9O_2)'' & \Big\}O \\ (C_8H_4O)^{\text{iv}} & \\ H_3 & \Big\}O_3. \end{array}$$

3. *Nornarcotine.*—From the observed reactions with the other bases, it appears probable that the reactions taking place when nornarcotine is heated with water, or treated with oxidizing agents, are

$$\overset{\text{Nornarcotine.}}{C_{19}H_{17}NO_7} = \overset{\text{Normeconin.}}{C_8H_6O_4} + \overset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3},$$

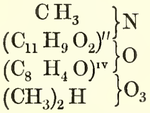
and

$$C_{19}H_{17}NO_7 + O = \overset{\text{Noropianic acid.}}{C_8H_6O_5} + \overset{\text{Cotarnimide.}}{C_{11}H_{11}NO_3}.$$

All experiments endeavouring to isolate any of its products of decomposition have as yet proved failures.

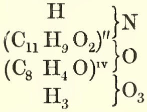
Its rational formula will probably be:

Narcotine.



$$\begin{array}{ll} CH_3 & \rbrace N \\ (C_{11}H_9O_2)'' & \\ (C_8\ H_4O)^{\text{iv}} & \rbrace O \\ (CH_3)_2H & \rbrace O_3 \end{array}$$

Nornarcotine.



$$\begin{array}{ll} H & \rbrace N \\ (C_{11}H_9O_2)'' & \\ (C_8\ H_4O)^{\text{iv}} & \rbrace O \\ H_3 & \rbrace O_3 \end{array}$$

4. *Cotarnine.*—When narcotine is oxidized by sulphuric acid and binoxide of manganese, and the resulting opianic acid separated by crystallization, and the manganese and cotarnine ultimately precipitated by excess of carbonate of sodium, on leaving the alkaline filtrate to spontaneous evaporation, long needle-shaped crystals of an inch or more in length occasionally form; these dissolve readily in alcohol, but only come out of the alcoholic solution as globules of oil and not as crystals. These crystals, after drying on blotting-paper, were found to lose 4·16 per cent. of water at 100°; having previously melted, the analyses of the residue led to the conclusion that these crystals were simply cotarnine with half a molecule of water of crystallization,

$$C_{12}H_{13}NO_3 + \tfrac{1}{2}H_2O,$$

this formula requiring 3·95 per cent. of loss at 100°.

Converted into platinum-salt, these crystals gave 23·08 and 23·00 per cent. of platinum; the cotarnine-salt requires theoretically 23·18 per cent.

All attempts to get oxidation products with certainty from cotarnine by various agents have failed; once only was cotarnic acid obtained by the action of dilute nitric acid (Part I. Phil. Trans. for 1863, p. 359). When cotarnine is evaporated with strong nitric acid on the water-bath to dryness, apophyllic acid was always found in the residue; the product, however, was always very small.

Miscellaneous Observations on Opianic Acid, Meconin, and Hemipinic Acid.

1. *Opianic Acid.*—When opianic acid is treated with bichromate of potassium and sulphuric acid in a dilute solution, hemipinic acid is formed, which may be obtained by extraction with ether, and may be separated from unaltered opianic acid by crystallization. In one experiment the water of crystallization was determined, and the purified acid converted into silver-salt.

0·6884 grm. silver-salt gave 0·3386 grm. metallic silver.

	Calculated. $C_{10}H_8Ag_2O_6$.	Found.
Silver per cent.	49·09	49·18

1·877 grm. of crystallized acid lost 0·1330 at 100°.

	Calculated.		Found.
$C_{10}H_{10}O_6$ . . .	226	92·63	——
H_2O . . .	18	7·37	7·09
$C_{10}H_{10}O_6 + H_2O$	244	100·00	

Opianic acid heated a few degrees above its melting-point (about 140° C.) loses moisture; the residue left is insoluble in cold water and dilute alkalies, but slowly dissolves on boiling, yielding opianates; it is nearly insoluble in cold alcohol, but little soluble in boiling alcohol; from a hot solution it separates on cooling in small shining crystals. These, when analyzed, led to the formula $C_{40}H_{38}O_{19}$, being apparently formed thus:

$$4(C_{10}H_{10}O_5) = H_2O + C_{40}H_{38}O_{19}.$$

The loss of weight on heating also confirms this reaction.

2. *Meconin.*—Meconin is apparently unaffected by heating in presence of water under pressure. Attempts to oxidize it by the following reagents all yielded negative results, however the conditions of the experiment were varied:—

Binoxide of manganese or bichromate of potassium and sulphuric acid. Permanganate of potassium, in acid and alkaline solutions. Binoxide of barium alone and with sulphuric acid. Ferric and platinic chlorides, &c. The action of nitrous acid gas on fused meconin gave rise only to the formation of nitro-meconin, which, when purified by recrytallization, gave the following numbers on analysis.

I. 0·3940 grm. of substance, dried at 100°, gave 0·7350 carbonic acid and 0·1360 water.

II. 0·3940 grm. of substance, dried at 100°, gave 0·7345 carbonic acid and 0·1260 water.

III. Nitrogen determination by LIEBIG's method gave the ratio of nitrogen to carbonic acid as 1 to ·210.

	Calculated.		Found.		
			I.	II.	III.
C_{10}	120	50·21	50·87	50·84	——
H_9	9	3·76	3·83	3·55	——
N	14	5·86	——	——	5·81
O_6	96	40·17	——	——	——
$C_{10}H_9(NO_2)O_4$	239	100·00			

The physical properties of this nitromeconin were carefully compared with those of nitromeconin prepared by the action of nitric acid on meconin, and found identical; in each case, however, there were found some slight differences from those usually ascribed to this substance (GERHARDT, iv. p. 82). Thus it was found to be almost insoluble in cold water, and only slightly soluble in boiling water, alcohol, ether, ammonia, potash, and soda; acids caused no alteration in the alkaline solution; aqueous and alcoholic solutions were not changed by ferrous, ferric, or cupric solutions:

Instead of: soluble in water, alcohol, and ether; very soluble in ammonia and alkalies, producing a red coloration; precipitable by acids from alkaline solution; its solutions yielding a precipitate with salts of iron and copper.

Attempts to form dinitromeconin were fruitless. Addition of sodium to fused meconin causes a copious evolution of hydrogen. The resulting compound when put into water reforms meconin and caustic soda.

3. *Hemipinic Acid.*—When hemipinic acid, dried at 100°, is heated, it melts at about 175°, and if kept at that temperature loses water; at higher temperatures the mass becomes slightly coloured, and at about 300° carbonic acid and aromatic vapours are evolved. The reaction occurring at 175°–180° is

$$C_{10}H_{10}O_6 = H_2O + C_{10}H_8O_5.$$

The body produced, which may be considered hemipinic anhydride, may be crystallized unaltered from *absolute* alcohol; after drying at 100° these crystals were analyzed.

10 grms. hemipinic acid lost at 175°–180° 0·791 grm.

	Calculated.		Found.
$C_{10}H_8O_5$	208	92·04	——
H_2O	18	7·96	7·91
$C_{10}H_{10}O_6$	226	100·00	

0·3050 grm. of anhydride gave 0·6450 carbonic acid and 0·1120 water.

	Calculated.		Found.
C_{10}	120	57·69	57·67
H_8	8	3·85	4·08
O_5	80	38·46	——
$C_{10}H_8O_5$	208	100·00	

If the anhydride be dissolved in alcohol containing a little water (ordinary spirit of about 90 per cent. alcohol), ethyl-hemipinic acid is formed; boiled with water it reforms hemipinic acid.

As formerly observed, ethyl-hemipinic acid may likewise be formed by passing dried hydrochloric acid gas into a solution of hemipinic acid (dried at 100°) in absolute alcohol; the substances prepared by these two methods are identical in physical properties, each having a strong tendency to separate from a hot aqueous solution on cooling in oily drops, and sometimes in feathery crystals containing half a molecule of water of crystallization.

Of these crystals 4·825 grms. lost at 100° 0·1870 grm.

	Calculated.		Found.
$C_{12}H_{14}O_6$	254	96·57	——
$\frac{1}{2}H_2O$	9	3·43	3·87
$C_{12}H_{14}O_6+$	263	100·00	

I. 0·3120 grm., dried at 100°, gave 0·6545 grm. carbonic acid and 0·1650 water.

II. 0·3460 grm. gave 0·7150 carbonic acid and 0·1670 water.

	Calculated.		Found.	
			I.	II.
C_{12}	144	56·69	57·21	56·36
H_{14}	14	5·51	5·87	5·37
O_6	96	37·80	——	——
$C_{10}H_9(C_2H_5)O_6$.	254	100·00		

I. was prepared by the action of hydrochloric acid gas on a solution of hemipinic acid in absolute alcohol.

II. prepared by the action of aqueous alcohol on hemipinic anhydride.

Ethyl-hemipinic acid digested under paraffin with strong hot hydrochloric acid becomes converted into hemipinic acid and chloride of ethyl,

$$C_{10}H_9(C_2H_5)O_6 + HCl = C_{10}H_{10}O_6 + C_2H_5Cl,$$

and the hemipinic acid is thus acted on, producing methyl-hypogallic acid.

Conclusion.—It may be as well to sum up as briefly as possible what has been done in the four portions of this research*.

1st. It has been proved, from the analyses of various samples of narcotine derived from various sources, that narcotine has always the same composition, viz. $C_{22}H_{23}NO_7$ (Part I. p. 346).

2nd. As stated by former observers, narcotine under the influence of oxidizing agents splits up into opianic acid and cotarnine.

$$C_{22}H_{23}NO_7 + O = C_{10}H_{10}O_5 + C_{12}H_{13}NO_3.$$

3rd. When heated a long time with water, or *per se* at 200°, narcotine splits up into meconin and cotarnine (Part IV. p. 667).

$$C_{22}H_{23}NO_7 = C_{10}H_{10}O_4 + C_{12}H_{13}NO_3.$$

4th. When narcotine is heated with excess of hydrochloric acid for a short time (about two hours), chloride of methyl is formed, and one atom of H substituted for one of CH_3 in the narcotine; if heated for a long time (some days), two atoms of H are substituted for two of CH_3; when heated with fuming hydriodic acid, iodide of methyl is formed in such quantities as proves that three atoms of H are substituted for three of CH_3. A series of homologous bases is thus formed (Rational formulæ, Part IV.), whose decompositions are analogous to those of narcotine.

5th. Cotarnine has been shown to have the formula

$$C_{12}H_{13}NO_3, \text{ and not } C_{13}H_{13}NO_3,$$

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* Parts I. and II. by Professor G. C. Foster and one of us, Phil. Trans. 1863, p. 345, and 1867, p. 657. Part III. 1869, p. 661. Part IV. 1869, p. 667.

and is capable of crystallizing with half a molecule, or with a whole molecule of water (Part I. p. 349, and Part IV. p. 673).

6th. When cotarnine is heated with dilute nitric acid, under certain not clearly understood conditions, cotarnic acid is produced together with methylamine,

$$C_{12}H_{13}NO_3 + 2H_2O = C_{11}H_{12}O_5 + C_3H_5N\,;$$

with strong nitric acid, as stated by previous observers, apophyllic acid is produced; other oxidizing agents give no definite results (Part I. p. 359, and Part IV. p. 673).

7th. When cotarnine is heated with strong hydrochloric acid, chloride of methyl is formed and hydrochlorate of cotarnamic acid,

$$C_{12}H_{13}NO_3 + H_2O + 2HCl = CH_3Cl + C_{11}H_{13}NO_4,\ HCl.$$

Hydriodic acid produces a similar reaction, only *one* equivalent of CH_3 being eliminated for one of cotarnine (Part I. p. 360).

8th. Opianic acid treated with bichromate of potassium and dilute sulphuric acid becomes oxidized to hemipinic acid (Part IV. p. 673),

$$C_{10}H_{10}O_5 + O = C_{10}H_{10}O_6.$$

9th. Opianic acid under the influence of nascent hydrogen (as with sodium-amalgam or zinc and sulphuric acid) is reduced to meconin (Part I. p. 354).

$$C_{10}H_{10}O_5 + H_2 = C_{10}H_{10}O_4 + H_2O.$$

10th. Opianic acid heated with caustic potash splits up into meconin and hemipinic acid (Part I. p. 352).

$$2C_{10}H_{10}O_5 = C_{10}H_{10}O_4 + C_{10}H_{10}O_6.$$

11th. When opianic acid is heated with excess of hydrochloric acid, chloride of methyl is formed, and hydrogen substituted for methyl in the opianic acid: it appears probable that two distinct substances are thus produced, noropianic acid and methyl-noropianic acid—the former by substitution of H_2 for $(CH_3)_2$, and the latter of H for CH_3; only the latter has been isolated in a pure state, the former decomposing spontaneously,

$$C_{10}H_{10}O_5 + 2HCl = C_8H_6O_5 + 2CH_3Cl,$$
$$C_{10}H_{10}O_5 + HCl = C_9H_8O_5 + CH_3Cl.$$

Hydriodic acid apparently produces similar decompositions; like opianic acid, methyl-noropianic acid is monobasic (Part II. p. 657).

12th. All experiments to oxidize meconin to opianic or hemipinic acids or any other product have proved failures.

13th. Meconin treated with excess of hydrochloric or hydriodic acid forms chloride or iodide of methyl, and a body derived from meconin by substitution of H for CH_3 (methyl-normeconin):

$$C_{10}H_{10}O_4 + HCl = C_9H_8O_4 + CH_3Cl.$$

Attempts to substitute H_2 for $(CH_3)_2$ did not yield anything capable of isolation in a pure state (Part II. p. 660).

14th. Hemipinic acid treated with reducing agents has in no case been reduced to opianic acid or meconin; nor have experiments to form opianic acid by the union of hemipinic acid and meconin proved successful; nor has hemipinic acid been oxidized to any other compound.

15th. When hemipinic acid is heated with excess of strong hydrochloric acid, chloride of methyl and carbonic acid are formed, and a new acid, methyl-hypogallic acid, in accordance with the following equation:—

$$C_{10}H_{10}O_6 + HCl = CH_3Cl + CO_2 + C_8H_8O_4.$$

When heated with hydriodic acid, hypogallic acid is formed, together with iodide of methyl and carbonic acid,

$$C_{10}H_{10}O_6 + 2HI = 2CH_3I + CO_2 + C_7H_6O_4$$

(Part II. p. 661).

16th. The observations of Anderson, that hemipinic acid is bibasic, have been confirmed, and an anhydride obtained by simple desiccation (Part IV. p. 675, and Part I. p. 354).

$$C_{10}H_{10}O_6 = H_2O + C_{10}H_8O_5.$$

Methyl-hypogallic acid, is however, monobasic.

17th. Hemipinic acid is capable of crystallizing with different amounts of water of crystallization, crystals with half a molecule, with a whole molecule, and with two molecules of water having been obtained (Part II. p. 662).

18th. All the reactions of narcotine and of its products of decomposition may be satisfactorily accounted for by the following rational formula:—

$$\begin{array}{ll} \mathrm{CH_3} & \rbrace\,\mathrm{N} \\ (\mathrm{C_{11}H_9O_2})'' & \rbrace\,\mathrm{O} \\ (\mathrm{C_8H_4O})^{\mathrm{IV}} & \\ (\mathrm{CH_3})_2\mathrm{H} & \rbrace\,\mathrm{O_3}. \end{array}$$

XXV. *Researches on Vanadium.*—Part II. *By* Henry E. Roscoe, *B.A., Ph.D., F.R.S.*

Received June 16,—Read June 17, 1869.

On the Chlorides of Vanadium and Metallic Vanadium.

In the first part of these researches* I stated that the nitride of vanadium forms the point from which the study of the vanadium compounds, properly so called, must be commenced. I now proceed to describe the composition and mode of preparation of the compounds of the metal with chlorine, and also the properties of the metal itself.

The process for preparing vanadium mononitride which I described in the last communication, was that proposed by Berzelius for obtaining the substance which he conceived to be metal. It consists in the action of dry ammoniacal gas upon vanadyl trichloride ($VO\,Cl_3$).

Owing, however, to the difficulty of properly regulating the very violent action which occurs when the two bodies come into contact, and the consequent loss of trichloride, this method was unsuited for the preparation of the nitride in quantity. Seeking for an easier and more economical method, I found that if the black residue left on calcining ammonium metavanadate in the air (probably an oxynitride) be heated to whiteness for a sufficiently long time in a current of dry ammoniacal gas, pure vanadium mononitride is left behind. A portion of ammonium-salt was placed in a platinum boat inside a porcelain tube, through which a stream of dry ammonia was passed. The tube was then heated to whiteness for three days.

Analysis 1.—Determination of Vanadium.

Weight of Nitride employed . . . 0·1705.

Constant weight of vanadium pentoxide obtained by roasting . . . . 0·2415.

Hence the nitride contained 79·6 per cent. of vanadium. The formula requires 78·6 per cent.

Determination of Nitrogen according to Simpson's method.

Weight of nitride taken . . . 0·2070.

Observed vol. of nitrogen (measured moist).	Pressure. millims.	Temp. °	Vol. at 0° and 760 millims.
111·2 vol.	746·2	17·0	100·5

(1 vol. =0·331 cub. centim.)

This corresponds to 20·2 per cent. of nitrogen.

Vanadium mononitride contains 21·4 per cent.

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* Bakerian Lecture, Philosophical Transactions, 1868, p. 1.

The substance used in the following analysis was prepared by heating about 3 to 4 grms. of the ammonia-salt in a platinum tube to whiteness in a current of dry ammonia. The tube was imbedded in a chalk crucible, and the central portions were heated to whiteness by the blast of a powerful blowpipe until no alteration of weight was observed. In this way, after a long and tedious series of operations, no less than 40 grms. of pure nitride (see analysis No. 2) was prepared.

Analysis No. 2.—Determination of Nitrogen.

Weight of nitride taken . . . 0·2250.

Observed vol. of nitrogen (measured moist).	Pressure. millims.	Temp. °	Vol. at 0° C. and 760 millims.
123·3	740·5	21·5	108·5

(1 vol. $=0·331$ cub. centim.)

This corresponds to 20·1 per cent. of nitrogen. A third and still more simple mode of obtaining the nitride is that of exposing the trioxide to the action of ammonia gas at a white heat. It is a remarkable fact, and one of which we know of but two other examples, that in presence of nitrogen and hydrogen the whole oxygen of an oxide is displaced by nitrogen.

THE CHLORIDES OF VANADIUM.

I have succeeded in preparing three chlorides of vanadium, viz. (1) vanadium tetrachloride, VCl_4, (2) vanadium trichloride, VCl_3, (3) vanadium dichloride, VCl_2.

(1) *Vanadium Tetrachloride*, VCl_4, molecular weight $=193·3$, vapour-density $=96·6$ $(H=1)$.—This chloride is formed as a dark reddish-brown volatile liquid when metallic vanadium or the mononitride is burnt in excess of chlorine.

Method 1.—The first method adopted for the preparation of the tetrachloride was by passing dry chlorine gas over the mononitride heated to redness; the whole of the nitride volatilizes, and a reddish-brown liquid is obtained. In one operation 16·96 grms. of the mononitride yielded, on treatment with excess of chlorine, 44·3 grms. of the crude tetrachloride, the theoretical yield being 50·1 grms. Owing to the inevitable presence of traces of oxide in the nitride, the first few drops of the distillate consisted of the more volatile light-yellow oxytrichloride, and this portion was collected separately before much of the dark tetrachloride had come over.

The crude product thus obtained was first saturated with chlorine, and then distilled upwards for some hours in a current of dry carbonic acid. On fractionating, the liquid was found to begin to boil at 148°, slowly rising to 154°, between which points the whole of the liquid came over.

A considerable quantity of a solid mass of peachblossom-coloured crystals, consisting of vanadium trichloride, remains behind in the bulb after each distillation. A second preparation of 50 grms. of the pure tetrachloride gave a constant boiling-point at 152°–154°.

Method 2.—When vanadium oxytrichloride is prepared according to BERZELIUS's reaction by passing dry chlorine over a mixture of the trioxide and charcoal heated to redness, the distillate possesses a port-wine colour, and it is only by frequent rectifications over sodium that the canary-yellow colour of the pure oxychloride is obtained. This coloration, though ascribed by SCHAFARIK to the presence of traces of vanadic acid, is really due, as I have formerly pointed out, to the presence of a dark-coloured vanadium chloride produced in the reaction and decomposed on rectification over sodium. This observation, coupled with the fact already made use of to demonstrate the existence of oxygen in the oxytrichloride, viz. that this substance yields up oxygen to red-hot charcoal, points the way to the second method for the preparation of the tetrachloride.

This consists in passing the vapour of the oxytrichloride, together with an excess of dry chlorine, slowly over a long column of pure sugar-charcoal heated to dull redness. This operation has to be repeated four or five times before the last traces of oxygen are withdrawn. Even after one distillation the product attains a dark reddish-brown tint, and boils at 152°; but it still contains 1 per cent. of oxygen, and needs three or four very slow repetitions of the process in order to obtain it perfectly pure. The solid trichloride is always found in the bulb from which the tetrachloride is distilled; but this, if carefully heated, slowly burns away in the excess of chlorine.

The portions of substance used for analyses 1, 2, and 3 were prepared from nitride, those in Nos. 4, 5, and 6 were obtained directly from the oxytrichloride. The chloride in analysis 4 was distilled three times over charcoal, and still contained a little oxygen; after another distillation (analysis 5) the oxygen was reduced to 0·2 per cent., and after a fifth distillation (analysis 6) the whole of the oxygen had been removed. The determinations were made by breaking a bulb containing a weighed quantity of substance in a closely stoppered bottle containing water; the chlorine was then estimated as silver-salt, nitric acid being added after the nitrate of silver, whilst the vanadium, either in the filtrate or in another portion of chloride, was weighed as pentoxide.

No.	Weight of tetrachloride found.	Silver chloride found.	Vanadium pentoxide found.	Percentages	
				of chlorine.	of vanadium.
1.	0·4272	1·2555	——	72·68	——
	0·6645	——	0·3195	——	27·02
2.	0·9644	2·8560	——	73·24	——
	1·0362	——	0·4890	——	26·52
3.	1·0438	3·0441	——	72·14	——
	0·9875	——	0·4632	——	26·36
4.	0·8935	2·6266	——	72·73	——
	1·1465	——	0·5440	——	26·65
5.	0·2940	0·8667	——	72·95	——
	0·4950	1·5760	0·2370	72·83	26·89
6.	0·4080	1·2086	0·1960	73·28	27·05

Hence we have for the composition of this chloride:

	Calculated.		Found.						Mean of 1,2,5&6.
			(1)	(2)	(3)	(4)	(5)	(6)	
V =	51·3	26·54	27·02	26·52	26·36	26·65	26·89	27·05	26·87
Cl_4 =	142·0	73·46	72·68	73·24	72·14	72·73	72·89	73·28	73·02
	193·3	100·00	99·70	99·76	98·50	99·38	99·78	100·33	99·89

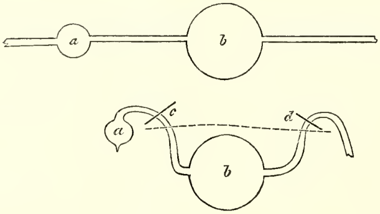
Vapour-density of Vanadium Tetrachloride.—Owing to the ease with which the tetrachloride decomposes into the trichloride and free chlorine, a solid residue is always left in the bulb when the determination is made by DUMAS's method in the ordinary way, and the experimental number is rather too high, as the following numbers show.

No. 1.—Weight of bulb and air at 10° C. and under 763·7 millims. . 11·1507 grms.
Weight of bulb and vapour at 219° and under 763·7 millims. 11·5900 grms.
Capacity of bulb 118 cub. centims., vol. of residual air 0·0 cub. centim.

Hence the vapour-density is found to be 99·06 (H=1) or 6·86 (air=1), the calculated density being 96·6 (H=1) or 6·69 (air=1).

In order to avoid the error arising from the deposition of a solid residue, an arrangement shown in fig. 1 was used. The tetrachloride was first placed in the small bulb (*a*); the large bulb (*b*) was then submerged, and the oil heated above the boiling-point of the chloride. The chloride was then boiled and the vapour passed through the bulb (*b*), and the tube sealed at *c*. The bulb was then turned round in the oil so as to bring the point (*c*) below the surface, and the temperature of the bath allowed to rise above 200° C.; and when the temperature had become constant, the tube was again sealed at *d*.

Fig. 1.



No. 2.—Weight of bulb and air at 15° C. and under 751 millims. . . 19·8945 grms.
Weight of bulb and vapour at 205° and under 758·1 millims. 20·3015 grms.
Capacity of bulb 112 cub. centims., residual air 2 cub. centims. No solid residue was left in the bulb.

Hence the vapour-density is found to be 96·6 (H=1), or 6·69 (air =1).

No. 3.—Another determination made at a higher temperature gave a somewhat lower number, indicating that a portion of the tetrachloride had been decomposed.

Weight of bulb and air 9° C. and under 762 millims. . . . 24·4722 grms.
Weight of bulb and vapour at 215° C. and under 762 millims. 25·0102 grms.
Capacity of bulb 169·5 cub. centims. No solid residue left in the bulb. Volume of mercury entering the bulb 157 cub. centims.

Hence the vapour-density is found to be 93·3 (H=1) or 6·48 (air =1).

Vanadium tetrachloride is a dark brownish-red, thickish liquid, which evolves white fumes when exposed to moist air. Its specific gravity was carefully determined at three temperatures, and found to be:

at 0° C.	1·8584
at 8° C.	1·8363
at 32° C.	1·8159.

It does not solidify at temperatures above —18° C.; nor does it at this, or any higher temperature, undergo any change of properties on treatment with chlorine. The boiling-point of vanadium tetrachloride is 154° C. (corrected) under a pressure of 760 millims.

Vanadium tetrachloride not only decomposes (as has been stated) on boiling into the trichloride and free chlorine, but the same decomposition takes place slowly at the ordinary temperature of the air. The liquid tetrachloride, sealed up in glass tubes and exposed to the light, was found on standing for some months to be changed to a dark blackish powder, whilst free chlorine was liberated in such quantity as not only to exhibit its characteristic greenish-yellow colour, but in several cases by its pressure to have burst the tubes. This powder on analysis was found to consist of the trichloride (see analysis, p. 685) moistened with tetrachloride; on removing this latter liquid in a current of dry carbonic acid at 170°, the pure violet solid trichloride was left behind. Thrown into water the tetrachloride is at once decomposed, yielding a blue solution identical in colour with the liquids obtained by the action of oxalic, sulphurous, or sulphydric acids on vanadic acid in solution, and containing a vanadous salt (derived from the tetroxide, V_2O_4).

In order to prove that a vanadous salt is formed when the tetrachloride is decomposed by water, the quantity of oxygen which this salt absorbs in conversion into vanadic acid was determined with a standard permanganate solution according to the method described in Part I. of these researches (Phil. Trans. 1868, p. 17).

Action of Potassium Permanganate on the aqueous solution of Vanadium Tetrachloride.

	(1)	(2)	(3)	(4)
Weight of VCl_4 taken	0·2375	0·5353	0·4628	0·5687
Cub. centim. of permanganate solution required (1 cub. centim. = 0·00066 grm. oxygen)	15·0	33·2	28·8	35·4
Percentage gain of oxygen found . .	4·17	4·09	4·10	4·09

The calculated percentage gain of oxygen according to the equation

$$2VCl_4 + O + 4H_2O = V_2O_5 + 8HCl \quad \text{is } 4{\cdot}14.$$

The solution of the tetrachloride in water does not bleach litmus-paper; but if the vapours of the boiling tetrachloride are condensed in water, a liquid is obtained which contains free chlorine, as it bleaches litmus-paper and liberates iodine from potassium iodide. At higher temperatures, as, for instance, when the vapours are led through a red-hot tube, much larger quantities of chlorine are evolved. Vanadium tetrachloride acts violently upon both dry alcohol and ether, giving in the first case a deep green, and in the second a deep red-coloured liquid. I am at present engaged with the examination of the products of this action.

Action of Bromine on Vanadium Tetrachloride.—Vanadium tetrachloride, heated with excess of bromine in a sealed tube to 180°, yielded a solid mass, which on drying in a stream of carbonic acid at 160°, presented the appearance of the peach-coloured trichloride, and subsequent analysis proved that this body was formed. It is thus seen that, heated in excess of both chlorine and bromine, the tetrachloride splits up into trichloride and free chlorine, so that vanadium does not readily form a pentad compound with the chlorous elements*.

(2) *Vanadium Trichloride,* $VCl_3 = 157{\cdot}8$.—The trichloride is a solid body, crystallizing in splendid peachblossom-coloured shining tables, closely resembling in appearance the crystals of chromium sesquichloride. It is non-volatile when heated in hydrogen, and decomposes when heated in the air, red fumes of oxytrichloride being given off in small quantity, whilst the solid mass glows with absorption of oxygen, forming the pentoxide. Heated in hydrogen it loses, first, one atom of chlorine, forming the dichloride (VCl_2), and afterwards, on exposure to a higher temperature, loses the whole of its chlorine, metallic vanadium being left as a grey lustrous powder.

Vanadium trichloride is an extremely hygroscopic substance; it instantly changes colour on exposure to moist air, deliquescing to a dark-brown liquid, which on the addition of a drop of hydrochloric acid becomes green, containing a solution of vanadium trioxide (V_2O_3), or rather of the corresponding hypovanadic salts.

The trichloride is obtained (1) by the slow decomposition of the tetrachloride at the ordinary atmospheric temperatures, (2) by the decompositions of the tetrachloride at its boiling-point, (3) together with dichloride, when the vapour of the tetrachloride is passed mixed with hydrogen through a red-hot tube. Method No. 2 is that which yields the trichloride in largest quantity and in the purest state, large quantities of the peach-coloured crystals remaining behind in the bulb-retort; and these only require heating in a current of carbon dioxide at 160° in order to yield the pure trichloride. The substance used in analysis (1) was obtained by the first method, that used for analyses 2, 3, and 4 was prepared by the second process.

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* The only other case of an element of a decidedly triad character yielding compounds of a tetrad nature, appears to be the nitrosyl-dichloride, $NOCl_2$, of GAY-LUSSAC, and the corresponding bromine compound, $NOBr_2$, discovered by LANDOLT.

No.	Weight of trichloride taken.	Silver chloride found.	Vanadium pentoxide found.	Percentages of chlorine.	Percentages of vanadium.
1.	1·6615	4·5704	0·9240	68·05	31·25
2.	0·2295	——	0·1320	——	32·31
	0·2550	0·6931	——	67·25	——
3.	0·1965	0·5298	0·1140	66·71	32·59
4.	0·1094	0·2993	——	67·67	——
	0·2188	——	0·1290	——	33·12

Hence we have for the composition of this chloride:

	Calculated.	Found. (1)	(2)	(3)	(4)	Mean.
V = 51·3	32·5	31·25	32·31	32·59	33·12	32·57
Cl_3=106·5	67·5	68·05	67·25	66·71	67·67	67·42
157·8	100·0	99·30	99·56	99·30	100·79	99·99

When the trichloride is thrown into water it does not at once dissolve, the peachblossom-coloured crystals floating in the liquid; these, however, gradually dissolve, forming a brown-coloured solution, which on addition of a drop of acid turns to a bright green colour, identical in tint with the liquid obtained by reducing vanadic acid in solution with nascent hydrogen evolved by magnesium, and containing a hypovanadic salt. Like the solution obtained by reduction, the green-coloured solution of the trichloride absorbs oxygen on standing, passing into the blue solution of the vanadous salts. A solution of hypovanadic salt obtained by dissolving 0·293 grm. of trichloride in water required 45 cub. centims. of permanganate solution in order to oxidize it completely (1 cub. centim. permanganate=0·00066 grm. oxygen). Hence the quantity of oxygen needed to oxidize the solution was 10·10 per cent. (on the trichloride), whilst that required by the formula $2VCl_3 + O_2 + 3H_2O = V_2O_5 + 6HCl$ is 10·14 per cent.

The specific gravity of vanadium trichloride at 18° is 3·00. Vanadium trichloride dissolves readily in absolute alcohol, forming a greenish-blue solution; in ether it also dissolves, giving a green-coloured solution.

(3) *Vanadium Dichloride*, VCl_2=122·3.—Vanadium dichloride is a solid body crystallizing in fine bright apple-green plates, having a micaceous lustre and an hexagonal form. It is prepared by passing the vapour of vanadium tetrachloride mixed with dry and pure hydrogen through a glass tube heated to dull redness. If the distillation of the tetrachloride be conducted slowly, and the mixture of vapour and hydrogen brought at once into the heated portion of the tube, the pure dichloride is deposited in light pearly scales, which can easily be shaken out of the tube. If the operation be conducted too quickly, or if the hydrogen be not present in large excess, a considerable quantity of

the peach-coloured trichloride is formed in the anterior portion of the tube, and the green crystals of dichloride collect in one spot and are fixed firmly to the glass. If the temperature be raised to a bright red heat during the preparation, the dichloride is further reduced, a black crystalline powder containing a mixture of lower chlorides and metal being produced, whilst the glass tube becomes opaque with formation of the silicon-vanadium compound. When heated for a long time in a platinum boat in a current of pure and dry hydrogen the dichloride loses all its chlorine, metallic vanadium being left in the form of bright greyish-white lustrous metallic grains. The dichloride prepared as above, gave the following analytical results:—

No.	Weight of dichloride taken.	Silver chloride found.	Vanadium pentoxide found.	Percentages of	
				chlorine.	vanadium.
1.	0·3317	0·7693	0·2510	57·40	42·53
2.	0·2490	0·5876	——	58·37	——
	0·2462	——	0·1832	——	41·80

Hence we have for the composition of the chloride:

		Calculated.	Found.		Mean.
			(1)	(2)	
$V =$	51·3	41·95	42·53	41·80	42·16
$Cl_2 =$	71·0	58·05	57·40	58·37	57·88
	122·3	100·00	99·93	100·17	100·04

Vanadium dichloride, when heated in hydrogen or in carbon dioxide, does not volatilize without decomposition. It is extremely hygroscopic, instantly absorbing moisture from the air, deliquescing to a brown liquid: a portion of this chloride exposed to the air for five minutes gained 4 per cent. in weight, and in standing for sixteen hours the increase amounted to 50 per cent. When thrown into water the dichloride does not at once dissolve, the scales floating on the water without becoming wet; soon, however, they dissolve, forming a violet-coloured liquid identical in tint with the solution of hypovanadous sulphate obtained by reducing a solution of vanadic acid in sulphuric acid by hydrogen evolved from zinc or sodium. Like this latter liquid, the solution of the dichloride in water acts as a very powerful reducing agent, bleaching litmus and indigo solutions.

A solution of hypovanadous salt obtained by dissolving 0·2875 grm. of vanadium dichloride in water required 81·8 cub. centims. of permanganate solution completely to oxidize it (1 cub. centim.$=$0·00066 grm. oxygen). Hence the percentage (on the dichloride) of oxygen needed to oxidize the solution was 18·78, whereas the formula $2V\,Cl_2 + O_3 + 2H_2O = V_2O_5 + 4H\,Cl$ requires 19·6 per cent.; the difference between the found and calculated numbers is due to the great difficulty of preventing the solution absorbing some little oxygen during the analysis, which must of course be conducted in an atmosphere of carbon dioxide. When the dichloride placed in a platinum boat is heated to whiteness in a current of dry ammonia, dense fumes of ammonium chloride are given off, and on cooling after an hour's heating, the boat contains vanadium mononitride in bronze-coloured pseudomorph crystals, which exhibit by reflected light a bright metallic lustre.

The specific gravity of vanadium dichloride at 18° C. is 3·23 as a mean of two well-agreeing determinations. Vanadium dichloride dissolves slowly in alcohol and in ether, giving in the one case a blue and in the other a greenish-yellow solution.

Metallic Vanadium, V=51·3.—From what we now know of the character of vanadium, we learn without surprise that the metal cannot be prepared in the free state by any of the methods given in the books.

BERZELIUS (POGG. Ann. vol. xx. p. 1) obtained a brilliant metallic scale by heating the oxytrichlorides, placed in a bulb-tube, in an atmosphere of ammonia; but this substance, as SCHAFARIK observes, is mononitride, and not metal. The great Swedish chemist also states that the metal can be prepared in a pulverulent form by exploding fused vanadic acid with potassium. The black powder which is obtained by lixiviating the fused mass is, however, not metal but an indefinite mixture of oxides. SCHAFARIK (Ann. der Ch. und Pharm. vol. cix. p. 97) describes as metal the brownish-yellow lustrous crystals obtained by passing the vapour of the oxytrichloride mixed with hydrogen through a red-hot tube. The body thus prepared, as I have already shown, is not the metal, but a mixture of the lower oxychlorides of vanadium.

JOHNSTON (N. Edin. Journ. of Sc. vol. v. pp. 166, 318) obtained a hard brittle metallic globule by reducing vanadic acid with carbon at a white heat; this was certainly not metallic vanadium, probably the alloy with silicon.

Although it appeared unlikely that any compound of vanadium containing oxygen would yield the metal by direct reduction, I have nevertheless repeated the above experiments, but without success. In order to test the second method proposed by BERZELIUS, the fused pentoxide was mixed with excess of sodium, and the mixture heated in a closed wrought-iron crucible; after the explosion the black mass was washed until free from alkali. A black powder is thus obtained which glitters when suspended in water, and this powder on oxidation only gained 16 per cent., showing that it contained even more oxygen than the trioxide.

JOHNSTON'S experiment was also repeated by exposing a mixture of trioxide, charcoal, and oil contained in a graphite crucible for several hours to the heat of a wind-furnace in which manganese can be fused. Not a trace of either a bead or metallic powder was obtained, and the black powder gained on oxidation only 16 per cent.

In order to ascertain whether under other circumstances the trioxide can be reduced, a portion of this oxide was heated to whiteness in a current of hydrogen, both when alone and mixed with excess of sodium; in neither case was the metal formed, a black residue of oxide remaining behind in the boats. The trioxide heated in a graphite crucible to bright redness with magnesium also yielded a black powder consisting of mixed oxides.

Another reaction consisted in passing the vapour of oxytrichloride mixed with hydrogen over metallic sodium heated in a porcelain boat; a black shining powder was thus obtained, which after lixiviation and drying was burnt to vanadium pentoxide, and gained only 11 per cent. in weight.

The only methods which promised possible results were:

1. The reduction of a vanadium chloride (free from oxygen) in hydrogen gas.
2. The reduction of the mononitride in a current of hydrogen.

The first of these methods has been found to be successful, the second does not appear to yield the metal; for in two experiments in which the mononitride was ignited in a platinum-tube to whiteness in a current of hydrogen, in one case for $3\frac{1}{2}$ and in another for 2 hours, the loss of weight was only 8·8 and 8·4 per cent. respectively, whereas the nitride must lose 21·4 per cent. when converted into the metal.

Reduction of the Metal from Vanadium Dichloride in Hydrogen.—The only method by which it has been found possible to obtain metallic vanadium is by the reduction of a chloride free from oxygen, in an atmosphere of perfectly pure hydrogen. Although this process appears simple enough, yet there is, I believe, no metal more difficult to obtain than vanadium.

This arises from the circumstance that while vanadium appears to be stable at ordinary atmospheric temperatures, it absorbs oxygen at a red heat with the greatest avidity, and that therefore every trace of air or of moisture must be excluded. Another difficulty consists in the preparation of sufficiently large quantities of the solid chlorides free from oxygen or moisture, as also in the length of time necessary in order to reduce these chlorides in hydrogen at a red heat, during which time diffusion (which can never be wholly prevented) brings traces of oxygen in contact with the heated metal.

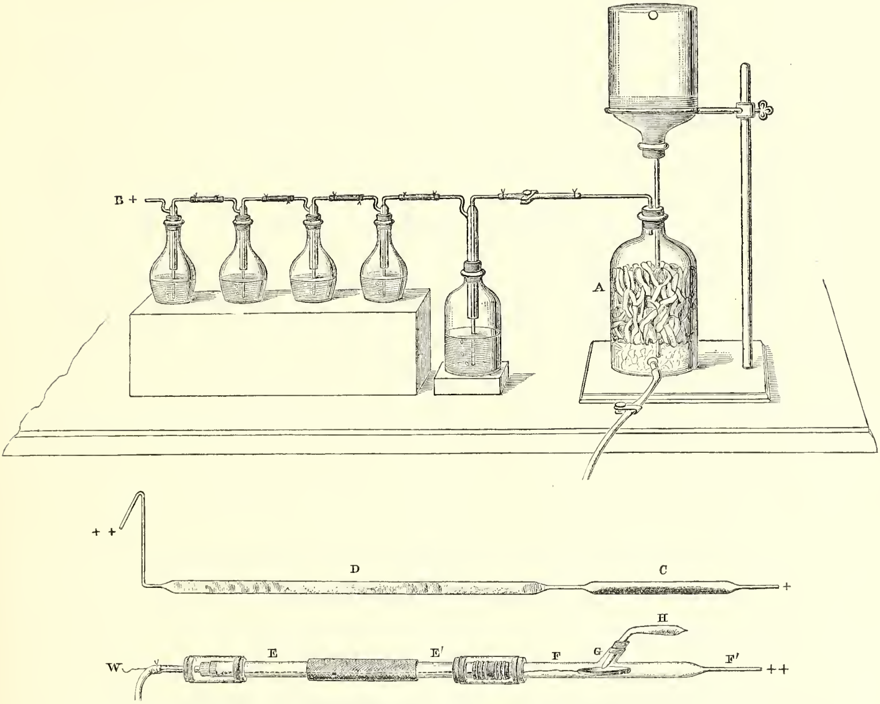
Then, again, the destructive action of the metal on glass and porcelain prevent these substances being used to contain the metal, whilst tubes of platinum and wrought iron become so porous at a red heat as to admit sufficient oxygen to convert the whole vanadium into trioxide. The only means which can be adopted is to heat the chloride in a platinum boat placed in a porcelain tube.

A laborious series of preliminary experiments on the reduction of the metal in this way proved that, in order to obtain a substance even approaching to the metal, many precautions must be taken, whilst they showed that, in spite of every care, it is extremely difficult to obtain the metal itself. Thus no less than ten experiments made by different modifications of this method yielded mixtures of metal with more or less oxide, of which the analyses showed an increase on complete oxidation varying from 60 to 67 per cent., that for pure metal being 78, whilst in every case in which the pure metal was prepared a considerable quantity of black sesquioxide was formed at the end of the boat nearest the inflow of hydrogen, showing that the source of error lay in the presence of diffused oxygen.

The apparatus which, after many alterations, was found best adapted for the preparation of the metal is represented on fig. 2.

It consists of a hydrogen generator (A) yielding a stream of hydrogen which can be kept constantly passing through the wash-bottles day and night for a week at a time, by occasionally adding fresh acid to the upper bottle and drawing off the zinc-sulphate solution from the lower bottle by the caoutchouc tube. The first wash-bottle contains a solution of lead acetate, the second silver nitrate, and the other three boiled sulphuric acid. In order to remove any trace of oxygen which may have accompanied the hydrogen arising either from diffusion or from air absorbed in the dilute acid used, a tube (C D) is attached to the end of the last washing bottle; the first portion of this tube contains a quantity of platinum sponge (C), which is heated to redness during the whole time the hydrogen is passing through the apparatus, whilst the further portion of the tube D is filled with phosphorus pentoxide and plugs of cotton-wool. The greatest care was taken to have all caoutchouc stoppers and joints made as tight as possible with copper wire and paraffin. At right angles to the drying-tube (C D) is placed the reducing arrangement shown in the lowest part of the drawing. This consists of a por-

Fig. 2.



celain tube (E E′) placed in a Hofmann's furnace and protected in the central portions, where it is heated, by an outer casing of sheet iron. The porcelain tube is connected with the hydrogen apparatus by means of the wide glass tube (F F′) provided with the tubulus (G), and narrowed down to join the drying-tube at F′. The joint between the porcelain and glass tubes is made of seamless caoutchouc well wired, and covered by an outer short glass cylinder, the space between the tubes and the cylinder being filled either with mercury or fused paraffin, and a similar joint is placed at the further end of the porcelain tube.

The introduction of the anhydrous dichloride without exposure to the air is effected by means of the tubulus (G), the dichloride being contained in the bent tube (H) in which it was prepared and sealed up in hydrogen. After the whole arrangement has been set up, the platinum boat being in position as shown in the figure, hydrogen is allowed to pass through the apparatus for twelve hours to dry it completely and clear out the air; the caoutchouc stopper of the tubulus is then withdrawn and the end of the tube containing the dichloride cut off, and the tube and stopper quickly replaced, so that the crystals lie in the horizontal portions of the tube. The bent tube is next so turned in the stopper that the crystals of dichloride fall out and are collected in the platinum boat placed below. This boat, charged with dichloride, is then drawn into the centre of the porcelain tube by means of the platinum wire, the end of which (W) passes through a small hole in the caoutchouc tube at the end of the apparatus. As soon as the boat is in position, the wire is cut off short at the end of the glass tube, a proper joint made, and an exit-tube attached dipping under sulphuric acid.

Before the porcelain tube is heated, the caoutchouc stopper of the tubulus is surrounded by a bath of paraffin, and the hydrogen is allowed to bubble through for six hours. The temperature of the porcelain tube is then gradually raised to the highest point (a bright red heat) which the Hofmann's furnace will yield, and kept constant until the reduction is complete. Torrents of hydrochloric acid gas at once come off, and the process must be continued for some hours after the last trace of acid can be detected in the hydrogen. The process lasts from forty to eighty hours, according as the quantity of dichloride employed varies from 1 to 3 or 4 grms.

Metallic vanadium prepared by reduction from the dichloride in hydrogen is a light whitish grey-coloured powder, which under the microscope reflects light most powerfully, and appears as a brilliant crystalline metallic mass possessing a silver-white lustre. It is remarkable that vanadium thus prepared does not oxidize or even tarnish in the air at the ordinary atmospheric temperature, nor does it decompose water at the ordinary temperature, and it may be moistened and dried *in vacuo* frequently without gaining in weight. Vanadium is neither volatile nor fusible when heated to redness in hydrogen. When the powdered metal is thrown into a flame, or rapidly heated in an excess of oxygen, it burns with the most brilliant scintillations, and when slowly heated in a current of air it glows brightly with absorption of oxygen, forming in the first place a brown oxide (V_2O or V_2O_2); and on further heating this oxide again glows, and passes through the black trioxide and blue tetroxide to pentoxide. The metal-powder is not magnetic, and it could not be pressed into a coherent form. Its specific gravity at 15° was found to be 5·5 as a mean of three determinations. The metal is not attacked by hydrochloric acid*, either when hot or cold; neither strong nor dilute sulphuric acid act on the metal in the cold, but when heated with the strong acid the metal slowly dissolves, giving a greenish-yellow solution. Hydrofluoric acid dissolves the metal slowly with evolution of hydrogen, and formation of a green solution, whilst nitric acid of all strengths oxidizes it with violence, evolving nitrous fumes and forming a blue liquid. Both hot and cold solutions of caustic soda are without action on the metal, but when fused with the hydroxide, hydrogen is evolved and a vanadate formed.

The metallic powder obtained by reduction contains a quantity of combined or absorbed hydrogen, the amount of which frequently rose up to 1·3 per cent. The weight of this hydrogen must be determined by burning the metal placed in a platinum boat, in a glass tube through which first a stream of dry air, and afterwards of pure oxygen is passed. A drying-tube placed in front of the combustion-tube gives the weight of water formed.

Analysis No. 1.—0·1365 grm. of substance, containing 0·0005 grm. of hydrogen, yielded on oxidation 0·2420 grm. of vanadium pentoxide in long clear needle-shaped crystals. Hence the percentage gain is 77·94, whereas that calculated from metal is 77·98.

Analysis No. 2.—0·2305 grm. of metal from a different preparation, containing 0·0022 grm. of hydrogen, yielded 0·3915 grm. V_2O_5. Hence the percentage gained was 70·8.

Metallic vanadium burns in excess of dry chlorine, forming the tetrachloride. A portion of dark reddish-brown chloride, formed by combustion of the metal in chlorine, gave the following results: 0·6958 grm. chloride yielded 1·9939 grm. Ag Cl, and 0·3383 grm. V_2O_5. Hence the chloride contained 70·8 per cent. of chlorine and 27·3 per cent. of vanadium; the difference between these and the theoretical numbers (73·46 and 26·54) being explained by the fact that the metal operated upon contained a slight admixture of oxide.

Heated in an atmosphere of pure nitrogen, metallic vanadium at once absorbs this gas and is converted into mononitride.

Vanadium attacks all glass or porcelain in which it is heated, a compound of silicon and the metal being formed. This compound coats all tubes of glass or porcelain in which the chlorides have been heated and reduced, as a grey lustrous metallic mirror, the formation of which renders the tubes very brittle and liable to crack. The silicon compound is not attacked by hydrochloric, and only slightly by nitric acid, but it tarnishes after a time on exposure. The metal also forms an alloy with platinum. All the platinum boats and tubes in which the reduction has been made are found after the operation to be completely saturated with vanadium, and require to be frequently ignited in the air, and as often boiled out with a solvent for vanadic acid, before they can be freed from the absorbed metal. If the platinum be frequently used for the reduction without this purification, it becomes brittle and dark-coloured from absorption of metal in quantity.

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* Hydrochloric acid readily dissolves the trioxide.

My best thanks are due to Messrs. Oelhofer and Finkelstein, who have ably assisted me during the progress of the above investigation.

XXVI. *On* Palæocoryne, *a Genus of Tubularine Hydrozoa from the Carboniferous Formation. By* P. Martin Duncan, *F.R.S., Sec. Geol. Soc., and* H. M. Jenkins, *F.G.S., Sec. Royal Agric. Soc.*

Received June 14,—Read June 17, 1869.

Contents.

I. Introduction.
II. Minute anatomy.
III. Zoological position.
IV. Terminology.
V. Classification.
VI. Description of the species.
VII. Remarks.
VIII. Palæontological relations.

I. *Introduction.*—The lower shales of the Carboniferous limestone series of Ayrshire and Lanarkshire are very fossiliferous in many places, and the organic remains found in them are remarkable for their perfect condition of preservation.

There are large numbers of fossil Brachiopoda, Polyzoa, Crinoidea, and Madreporaria in the black shales of Roughwood and Broadstone, near Beith, and of Auchenskeigh, and of Gare, near Carluke. Associated with the Polyzoa are numerous small pedunculated radiata, whose external appearance differs from that of any extinct organism hitherto discovered.

They are usually found attached to the margins of the polyzoarium of *Fenestellæ*, or they may be discovered in a more or less fragmentary condition amongst the small pieces of broken Polyzoa and Crinoid stems which compose the fossiliferous layers of the shales. The attachment is by a dactylose base, which, when broken or cut, is proved to be cellular internally. The base contracts as it increases in height, and is continued upwards in the form of a cylindrical stem, which is faintly enlarged in its middle portion, and which is surmounted by a symmetrical structure resembling a reversed obtuse cone, the margin of whose base is produced into several tentacular processes.

The tentacular processes are in one whorl; they radiate from the margin of the upper part of the conical body, and they are separate at their point of origin. They are long, slender, tapering, and occasionally irregular in their length and thickness. Their direction is not at right angles to the stem, but they project obliquely upwards and outwards. The inferior surface of the tentacles is continuous with the outside of the conical body, and the superior surface is continued on to the upper surface, or reversed base, of the conical body, which has a much greater diameter than the supporting stem. This upper surface is flat in many specimens, but in a few it is elevated centrally into a crateriform process, which has an opening on its apex.

The height of the form is not more than $\frac{1}{10}$ inch, and the length of the longest tentacular process is about $\frac{1}{2}$ inch. The fossils are composed of carbonate of lime.

The symmetry and elegance of the little fossil are heightened by its minute but elaborate ornamentation. The proportions of the body, stem, and base are those of the most symmetrical architectural pillars; and the elegant outlines of the tentacular processes are rendered more striking and less monotonous by the presence of spicules and of long fluted lines of delicate depressions, whose little spines are occasionally preserved. The upper surface of the body is granular, and the stem is ornamented with longitudinal flutings and minute processes.

The general appearance of the fossil is that of a long straight-armed starfish reversed and fixed on a stiff stem with an expanded base.

There was more than one species of this organism in the blocks of shale examined*, and many specimens had their tentacular processes in different stages of development. It is evident that the organism had attached itself to *Fenestellæ*, but that it did not derive its nourishment from that Polyzoon. The delicate polypary of the *Fenestellæ* being slightly flexible and containing great numbers of ciliated Polyzoa, they afforded an excellent foundation and support to the stiff-stalked and rigid-limbed little radiate animal that forms the subject of this communication.

The associated Brachiopoda, Madreporaria, Crinoidea, Polyzoa, and the small pedunculated radiata were dwellers in rather deep water. Their modern representatives live at considerable depths; and the stoneless condition of the shales in which the fossils are found, and the perfect condition of the organic remains, indicate their deposition on a sea-bottom where there was no rapid current, but, on the contrary, a comparatively quiet state of things.

II. *Minute anatomy.*—The base, stem, body, and tentacular processes are hollow, and their cavity is continuous throughout the cells of the attachment, the ascending stem, the expanding body, and the radiating processes; and it has one upper and central communication with the outside. The cavity occupies a large proportion of the animal, and the enclosing hard structure is but a thin shell.

The body is not, however, a simple hollow cavity surrounded by a thin layer of hard structure through which the canal-like cavities of the tentacular processes enter; for these processes continue to be separate for some distance within the body, and their canals only unite very centrally with the cavity of the body.

The cavity of the body, thus enlarged, opens below into that of the stem, and above by means of a very small foramen, the oral orifice.

This orifice is closed when the upper surface of the body is flat, and then only a continuous granular layer of hard tissue is to be seen. Slight scraping with a knife soon exposes the orifice.

When the upper surface of the body is swollen and projecting, the central opening is at the extremity of the crateriform process, whose sides are marked with radiating lines very much like the margins of the oral plates in young *Pentacrini**. It would appear that this projection depended upon the condition of the nutrition of the animal before its entombment.

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* The specimens were discovered and collected by James Thomson, Esq., F.G.S., of Glasgow, and by him forwarded to us for description, and for the determination of the zoological position and affinities of the fossils.

The tentacular canals diminish in size with the length of the processes, and they are not continuous with the irregular spinules; but whenever the distal end of a long tentacle can be examined, a small central puckering is observed on it. It is very probable that the cavity of the tentacular process was continued into a soft and ciliated prolongation through this orifice. The union of the tentacular canals with the cavity of the body produces, in transverse sections of that part of the animal, an appearance like that of the rosette in the Crinoidea.

Transverse and longitudinal sections of the stem show the papillary and faintly spinose and pitted ornamentation of the outside of the hard parts, and delicate striæ running from the inside externally and horizontally, but there is nothing like an opening between the large internal cavity and the outside to be seen.

The base is formed of the external hard tissue which grasps and includes its own cellular structures and those of the Polyzoon. Its length varies.

III. *Zoological position.*—The absence of any structures resembling basal or baso-radial plates and of joints in the tentacular processes, renders the opinion that the fossil should be referred to the Echinodermata untenable.

The isolation of the individuals, each possessing but one external opening, and the general characters of the tentacular processes, preclude any reference to the Polyzoa.

The internal anatomy, the structure of the hard parts, and the nature of the tentacular processes, prevent classification with the Zoantharia.

Were it not for the calcareous investments, there would be no difficulty in admitting the fossil amongst the Hydrozoa; and had we not been able to avail ourselves of the affinities of the very anomalous genus *Bimeria* (Wright) the difficulty could hardly have been overcome.

There are many kinds of periderm amongst the recent Tubularine Hydrozoa, and the genera *Monocaulos* (Allman), *Corymorpha* (Allman), *Eudendrium* (Ehren.), and *Bimeria* (Wright), afford examples of a gradation in structure from a condition of great tenuity and delicacy to one of a chitinous character, and up to the peculiar pergamentaceous nature of the polypary of the last-named genus.

But the cœnosarc of *Monocaulos*, *Corymorpha*, and *Eudendrium* is the only part covered by the periderm. In the genus *Bimeria*, however, the semi-solid investment not only covers the cœnosarc, but is also continued over the greater part of the tentacles and over the upper part of the body, leaving an opening for the mouth on the metastome.

The resemblance of the fossil under consideration to the trophosome of *Bimeria vestita* (Wright) is very decided.

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* Researches on the Structure, Physiology, and Development of *Antedon* (*Comatula*, Lamk.) *rosaceus*. By William B. Carpenter, M.D., F.R.S., Phil. Trans. Roy. Soc. vol. clvi. p. 671.

Bimeria vestita (Wright) was found on the Bimer Rock on the west coast of Ireland, and its organs of nutrition and generation have been examined by its discoverer and Dr. Allman*.

In its early period of trophosome it is a simple or solitary hydrozoon; but during growth it becomes compound, and every succeeding branch is terminated by a tentaculate polypite.

The gonosome of the fossil organism may be traced in a stout projection from the junction of the stem with the body in one specimen†, and possibly in the presence of some circular depressions on the under surface of the tentacular processes in others.

As yet our material is not sufficient to enable us to decide upon the nature of the gonosome.

The presence of the spinose ornamentation and the compact nature of the periderm of the new form distinguish it from all other Hydrozoa. It is probable that, like *Bimeria vestita*, the tentacular processes of the fossil form had ciliated ends projecting beyond the periderm, and that the metastome projected at certain times and not invariably.

The zoological position of the fossil is amongst the Hydrozoa in the Order Tubularidæ and near the Eudendridæ.

IV. *Terminology.*—Being satisfied that the fossil should be admitted amongst the Hydrozoa, its anatomical structures must assume the following names. The dactylose base is the hydrorhiza, the stem is the hydrocaulus, the tentacular body with the broad upper surface, with or without an evident metastome, is the polypite. The ornamented hard external tissue is the periderm or polypary. The faintly traced generative structures constitute the gonosome, and the rest are embraced under the term trophosome. The term hydrosome refers to the whole.

V. *Classification.*—

Class Hydrozoa.
Order Tubularidæ.
Family Palæocorynidæ.
Genus Palæocoryne.

Family Palæocorynidæ.—Hydrozoa, whose hydrosoma is fixed by a hydrorhiza. Polypary organized, calcareous, dense and ornamented, investing the whole of the Hydrozoon, except the opening for the mouth and probably the terminations of the tentacles.

Tentacular processes long, and more or less spined.

Genus Palæocoryne, gen. nov.

Trophosome solitary. Tentacles few in number, long, in one verticel and ornamented.

Hydrocaulus shorter than the tentacles, straight, cylindrical, broad and rigid, its ornamentation definite. Polypite either flat on the oral aspect, or elevated more or less to form a metastome, the periderm being granular and marked with ridges. Hydrorhiza more or less cellular within, broad and dactylose.

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* T. Strethill Wright, M.D., Edin. New. Phil. Journ. vol. x. N. S. 859, p. 105. Allman, Ann. Mag. Nat. Hist. S. 3. No. 77, p. 355 (1864).

† Plate LXVI. fig. 11.

Gonosome.—Gonoblastidia at the junction of the hydrocaulus and the body of the polypite (?).

VI. *Description of the species.*—

1. *Palæocoryne Scoticum*, nobis.
2. *Palæocoryne radiatum*, nobis.

1. PALÆOCORYNE SCOTICUM. Plate LXVI. figs. 1 & 6. The trophosome is short. The hydrorhiza and the body of the polypite are nearly equal in size. The tentacles are about seven in number; they are, when fully developed, several times longer than the hydrocaulus and are slender, tapering and irregular in their length, size, and distance; their periderm is spined, and is marked with pits, grooves, dentations, and serrations; and it is generally ornamented above and below with ridges, which are continued on to the oral surface or downwards on to the sides of the polypite. The hydrocaulus is slender, terete or slightly polygonal, and its periderm is ornamented with alternately larger and smaller flutings, pits, and small spines.

The hydrorhiza has one or more cellular processes, and an ornamented polypary, and it grasps the margin of foreign bodies.

The oral surface is either flat or slightly concave and granular; or is convex and marked with radiating ridges terminating at the oral orifice and limiting the metastome. The oral opening is often invisible.

Height of fossil without tentacles $\frac{1}{10}$ inch. Length of tentacles (extreme) $\frac{1}{2}$ inch.

Fixed on *Fenestellæ* in the lower shales of the Carboniferous formation of Ayrshire and Lanarkshire.

2. PALÆOCORYNE RADIATUM. Plate LXVI. figs. 2, 5–8, 11. *Trophosome.*—The polypite body is small. The tentacles are from seven to eleven in number; they are moderately long, equidistant, subequal, rounded, tapering, closely striated, faintly spined, and rarely marked with lateral dentations. The hydrocaulus is short, cylindrical, faintly bulging, ornamented with subequal rounded flutings, the periderm being abundantly pitted, but not spined.

The oral surface is concave, and the projecting metastome is small.

The *gonosome.*—Processes covered with periderm are developed from the base of the polypite near its junction with the hydrocaulus. Gonoblastidia?

Localities.—Auchenskeigh and Roughwood, Ayrshire, in the lower Carboniferous shales.

The tentacles of *Palæocoryne radiatum* are shorter, stouter, and more finely striated than those of the other species.

VII. *Remarks.*—The tenuity and length of the fully developed tentacles, and the manner in which some of them are curved and waved, indicate that, although their periderm was dense, there was some power of movement in them; otherwise the slightest contact with a moving body would have fractured them. There is much diversity in the length of the tentacles and in their thickness, and most of them are marked with transverse cracks, the result of post-mortem violence.

The distal ends of the longest tentacles are very delicate, yet a long ciliated process might pass out from the free termination as in *Bimeria vestita*. The metastome is visible in a specimen of both species; but usually the granular polypary of the oral surface shows no opening, and it is only when the exact spot of the mouth is worn down to in sections that any trace of it can be found. The ridges of this surface are usually connected by festoon ornamentation.

The development of the periderm of the hydrocaulus from the cœnosarc may be inferred; for in longitudinal sections there is an appearance of horizontal striation, and the striæ indicate the former projection into the periderm of processes belonging to the cœnosarc.

VIII. *Palæontological relations.*—Although the Hydrozoa are very abundant in fresh and in sea-water, they are very rarely found as fossils. Their delicate structure and peculiar periderm would prevent their fossilization under ordinary circumstances.

M. Fischer[*] has distinguished Hydractiniæ in the Cainozoic deposits of Dax and in the Cenomanien of Mans; and the impressions of Medusæ have been discovered in the Jurassic strata of Solenhofen.

In the Silurian division of the Palæozoic strata are the fossils called Graptolites, which are considered by some Palæontologists to be Hydrozoa. The theory announced by Agassiz respecting the Hydroidean characters of the tabulate division of the Sclerodermic Zoantharia is still under consideration and requires confirmation.

The interest of the discovery of the *Palæocorynidæ* in the moderately deep-sea deposits of the Carboniferous period is therefore great. The form of the Medusæ of the species is of course unknown, but it is evident that they floated in the estuaries and shallow seas, and perhaps in the oceans of those Palæozoic days, and deposited the ova which produced the trophosomes that have descended to the present time in a fossil condition.

The choice by both species of the margin of a polypary of *Fenestella* for their resting-place, suggests that some portions of the economy of the Polyzoon were beneficial to their more or less rigid associates. Doubtless the gentle movement of the frond-like mass and the currents produced by the numberless polypes contributed to the supply of food for the Hydrozoa. The ornamentation of the *Fenestella* is occasionally repeated on the tentacles of the *Palæocoryne Scoticum* in a very striking manner.

Note.—The calcareous investment of *Palæocoryne Scoticum* and *Palæocoryne radiatum* has not the peculiar cleavage of the hard structures of the Echinodermata.—September 6, 1869.

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[*] Bull. de la Soc. Géol. de France, 2 série, tome xxiv. p. 689.

DESCRIPTION OF THE PLATE.

PLATE LXVI.

Illustrating the Structure of Palæocoryne.

Fig. 1. Portion of the trophosome of *Palæocoryne Scoticum*, showing the fluted periderm of the hydrocaulus, the cellular and dactylose processes of the hydrorhiza, and the base of three of the tentacles Magnified 15 diameters.

Fig. 2. Portion of the trophosome of *Palæocoryne radiatum*, showing the same organs as fig. 1. Magnified 15 diameters.

Figs. 3 & 4. Partial sections of similar portions of the trophosome of two individuals, showing the cellular nature of the hydrorhiza, the tubular nature of the hydrocaulus, and its connexion with the cavity of the polypite and the tubulated tentacles. Magnified 15 diameters.

Fig. 5. Hydrocaulus and polypite of *Palæocoryne radiatum*, showing the number and arrangement of the tentacles. Magnified 15 diameters.

Fig. 6. Hydrocaulus of *Palæocoryne Scoticum*, showing the relation of the hydrozoon to a portion of a polyzoarium of *Fenestella*. Magnified 15 diameters.

Fig. 7. Polypite, metastome, and tentacles of a specimen of *Palæocoryne radiatum*, showing their external structure and relations. Magnified 10 diameters.

Fig. 8. Side view of a trophosome of *Palæocoryne radiatum*, showing the hydrorhiza, hydrocaulus, polypite, and portions of the tentacles. Magnified 15 diameters.

Fig. 9. Upper surface of the polypite of a species of *Palæocoryne*, showing the external ornamentation and the arrangement of the tentacles. Magnified 30 diameters.

Fig. 10. A similar specimen ground down to show the internal structure of the polypite. Magnified 30 diameters.

Fig. 11. Portion of the hydrosome of *Palæocoryne radiatum*, showing the upper surface of the polypite, portions of some of the tentacles, part of the hydrocaulus, and an appendage to the latter supposed to form part of the gonosome. Magnified 25 diameters.

Duncan & Jenkins. *Phil. Trans.* MDCCCLXIX. *Plate* LXVI.

Fig. 7.
× 10.

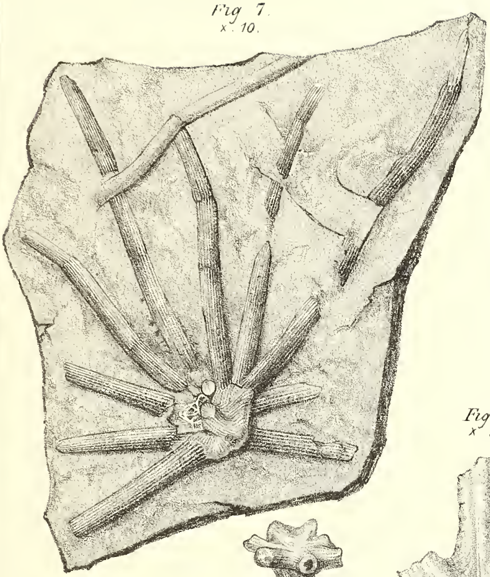


Fig. 6.
× 15.

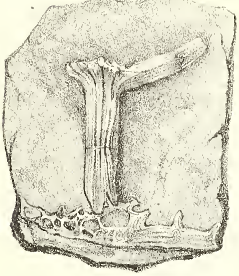
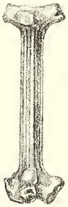


Fig 1.



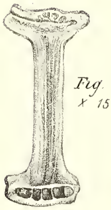


Fig. 4.
× 15.

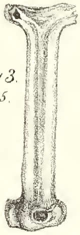
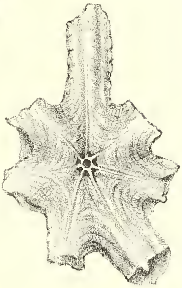


Fig 3.
× 15.

Fig 10.
× 30.



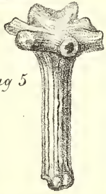
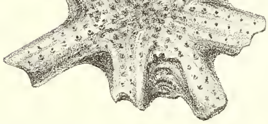


Fig 5

Fig 9
× 30



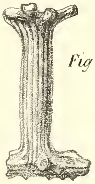


Fig 2.

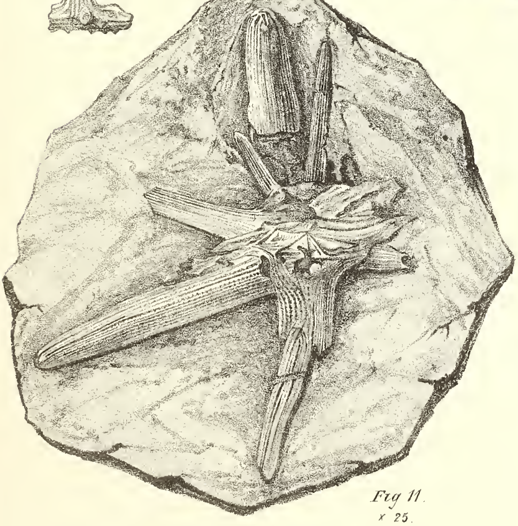


Fig 11.
× 25.

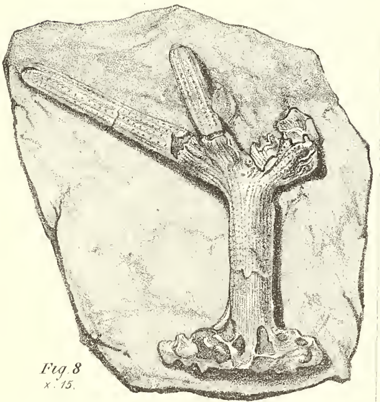


Fig. 8
× 15.

E M Williams S C

M & N Hanhart imp

PALÆCORYNE.

BRITISH MUSEUM NATURAL HISTORY

XXVII. *On* Holtenia, *a Genus of Vitreous Sponges. By* WYVILLE THOMSON, *LL.D., F.R.S., Professor of Natural Science in Queen's College, Belfast.*

Received June 16,—Read June 17, 1869.

DURING the deep-sea dredging cruise of Her Majesty's Ship 'Lightning' in the autumn of the year 1868, the 6th of September was occupied in dredging at the depth of 530 fathoms in latitude 59° 36′ N., and longitude 7° 20′ W., only about 20 miles beyond the 100-fathom line of the Coast Survey of Scotland, slightly to the westward of north of the Butt of the Lews. The minimum temperature indicated by the mean of three thermometers (which registered 47°, 47°·5, and 47°·5 FAHR. respectively) was 47°·3 FAHR, the surface-temperature being 52°·5 FAHR.

During the day there were four successful hauls of the dredge, which came up each time full of a pale-grey tenacious mud, consisting in a great measure of minute amorphous particles of carbonate of lime mixed with "coccoliths" and "coccospheres." There was only a small proportion of the *Globigerinæ* and other minute Rhizopods which are so abundant and characteristic over the whole of the warm or "Gulf-stream" area of the North Atlantic. The mud was glairy, as if it had been mixed with white of egg; and it contained disseminated through it an immense quantity of extremely delicate siliceous organisms, spicules of sponges, and the shells of Radiolarians and Diatoms. Large Rhizopods of the genera *Astrorhiza*, *Rhabdammina*, *Cristellaria*, *Cornuspira*, and others were abundant; and there was a somewhat scanty sprinkling of small forms belonging to the higher groups, Echinoderms, Annulosa, and Mollusca. Besides a number of dead shells, chiefly of the Boreal or Scandinavian type, and several undescribed Echinoderms and Crustaceans, the following species were procured living.

ECHINODERMATA.

†*Rhizocrinus Loffotensis*, Sars.
Amphiura filiformis, Müller.
Amphiura tenuispina, Ljungman.
Amphiura Ballii, Thompson.
†*Amphiura Abyssicola*, Sars.
†*Ophiacantha spinulosa*, Müller and Troschel.
†*Echinocucumis typica*, Sars.
†*Thyone alticola*, Norman, MSS.

CRUSTACEA.

Phoxus plumosus, Kröyer.
Ampelisca æquicornis, Lilljeborg.
†*Œdiceros spinicornis*, Norman, MSS.
Haploops tubicola, Lilljeborg.
†*Diastylis* (sp.).
Pagurus pubescens, Kröyer.
Galathea dispersa, Bate.

MOLLUSCA.

Terebratula cranium, Müll.
Crania anomala, Müll.
Arca nodulosa, Müll.
Pecten vitreus, Chemnitz.
Lucina borealis, L.
Astarte compressa, Montfort.
Venus casina, L.
Mactra solida, L.
Neæra costellata, Deshayes.
Columbella Haliæti, Jeffreys[*].

The species marked with a dagger are new to the British area. The assemblage of higher forms presents generally the character of the abyssal fauna of the Boreal region. Two specimens were procured of the specially interesting *Rhizocrinus Loffotensis*, Sars, a small Crinoid belonging to the family Apiocrinidæ, and nearly allied to the fossil *Bourgueticrinus* of the Chalk. *Rhizocrinus* was discovered in the year 1864 by M. G. O. Sars, in 300 fathoms water, at the Loffoten Islands within the Arctic Circle[†], and has since been dredged by M. de Pourtales on the opposite edge of the Gulf-stream, off the coast of Florida[‡].

Besides tangled masses of long spicules and fragments of siliceous sponges, we procured during the day about fifty specimens of sponges more or less complete. These were referable to four genera, one of which was the genus *Hyalonema*, Gray, of which we got two species closely resembling the singular glass-rope sponges of Japan and the coast of Portugal; and the remaining three genera were new to science.

One of these new genera is the subject of the present Memoir.

HOLTENIA[§] (new genus).

H. CARPENTERI[||] (new species). Plates LXVII. to LXXI.

Provisional characters and general description.—The body of the sponge is globular, elliptical, or subcylindrical. The length of apparently mature examples is from[¶] 90 to 110$^{\text{mm}}$, and the extreme width from 70 to 90. The outer wall is formed of a framework of large separate siliceous spicules, whose rays are so arranged as to give the whole surface a stellate appearance. The external surface is invested with a delicate network of sarcode-threads which define inhalent pores. At the top of the sponge there is one large oscular opening about 30^{mm} in diameter, whence a cylindrical cavity passes vertically into the substance of the sponge to a depth of 55. This oscular cavity is cupped beneath, and lined by a network with the same general character as the external network of the sponge. The osculum is fringed by a close range of siliceous spicules placed vertically. The sponge-body between the oscular and external walls is composed of a loose spongy mass of consistent sarcode containing a multitude of minute brownish or greyish granules which make it semiopaque, supported by an irregular framework of stellate siliceous spicules, and containing numerous minute feathered spicules and amphidisci. Close beneath the outer wall the sponge-substance is hollowed into wide anastomosing sinuses, which surround and separate perpendicular spongy columns which support the external stellate wall. From the surface of the upper third of the sponge, bunches of rigid spicules project outwards and upwards from the substance of the sponge through the outer wall; and from the surface of the lower third of the sponge, bundles of enormously long siliceous threads, coated with glairy sarcode, pass out to be diffused to a great distance through the chalk-mud, in which the sponge is buried nearly to the lip.

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[*] The above list of Echinoderms and Crustacea is on the authority of the Rev. Alfred Merle Norman, and of Mollusca on that of J. Gwyn Jeffreys, F.R.S. The complete lists are in preparation, and will be published hereafter.

[†] Mémoires pour servir à la connaissance des Crinoïdes Vivants, par Michael Sars, Christiania, 1868.

[‡] "Contributions to the Fauna of the Gulf-stream at Great Depths, by L. F. de Pourtales," Bulletin of the Museum of Comparative Zoology, at Harvard College, Cambridge, Mass., No. 7, 1868.

[§] I have much pleasure in naming this genus in compliment to His Excellency M. Holten, the accomplished Governor of the Faroe Islands, who showed the most intelligent interest in the success of our researches, and to whom we were indebted for the most friendly hospitality.

[||] As this is the most striking of the new forms which have hitherto rewarded our labours in the deep sea, I dedicate it to my distinguished colleague Dr. W. B. Carpenter, V.P.R.S.

[¶] The metrical system of measurement is employed throughout.

Four specimens only of this species have as yet been found, at a depth of 530 fathoms in lat. 59° 36′ N., long. 7° 20′ W. One of these, figured in Plate LXVII. of the present Memoir, has the body about a decimeter in length by 8 centimeters in width; the outline is elliptical. A second specimen, figured in section, Plate LXIX. fig. 1, is nearly spherical, about 9 centimeters in diameter; a third, in the British Museum, is more cylindrical in form, about a decimeter in length by 7 centimeters in width; and the fourth, in the possession of Dr. Carpenter, is rather smaller and nearly globular. These four specimens were all procured at one haul of the dredge. They were brought up alive, and with higher organisms, clams and starfishes, also living, attached to them. Unfortunately, from the state of the weather, we were unable to observe them in a living state; we were obliged to put them at once into spirit.

The Structure of the Sponge.

The siliceous spicules.—The spicules which enter into the composition of the sponge may be conveniently divided into three groups, the spicules of the sponge-body, the spicules of the beard, and the spicules of the sarcode.

1. *The Spicules of the Sponge-body.*—The spicule which enters almost exclusively into the structure of the framework of the sponge-body, forming the stellate trellis of the outer wall and of the wall of the inner exhalent cavity, and supporting and defining the trabeculæ of the areolated sponge-substance, is formed on the hexradiate-stellate type; usually, however, only five rays are developed, so that the spicule is quinqueradiate. There are two well-marked sizes of this spicule. The larger form by the symmetrical distribution of their rays, the siliceous framework of the large stars of the outer and inner walls; while the smaller, which are altogether much more delicate in their proportions, support the small secondary stars of the walls, and the meshes of the sponge-substance.

The large spicules of the walls are quinqueradiate (Plate LXVIII. figs. 1, 2, Plate LXIX. figs. 2, 4, 5). Four of the rays, which represent the four secondary rays of a hexradiate spicule, spread nearly on a plane. They spread, however, irregularly, each branch curving independently to suit the plan of structure and the pattern of the particular portion of the network in which it is developed. This irregularity is sometimes extreme, two of the branches in some cases running nearly parallel with one another, while the other two diverge widely; and sometimes all the four branches curve round and run nearly in one direction; more usually, however, they form a more or less regular cross at their origin (Plate LXIX. figs. 2–4). The fifth ray, which represents one half of the primary shaft of a hexradiate spicule, is essentially at right angles to the other four; but this branch is likewise irregular and flexible in its distribution. It usually dips down more or less perpendicularly into one of the columns of the sponge-body, which it thus serves to attach to the wall. Opposite to the point of junction of the vertical ray with the four transverse rays, there is frequently a more or less distinct rounded elevation or tubercle. This tubercle undoubtedly represents the sixth ray, the continuation of the primary axis of the spicule. In some cases, which occur however more frequently in the smaller spicules of this type, the tubercle is developed into a branch, and the spicule becomes hexradiate, recalling the ordinary hexradiate spicule of the sponge-mass of *Hyalonema*.

The length from point to point of two of the cross branches of one of these spicules is about 15^{mm}, and the length of the azygous arm from 7·5 to 10. The diameter of the ray near the point of decussation is from ·1 to ·12. The central cavity in these spicules is very distinct. At the point of origin of the rays it divides evidently into five, and when the prominence representing the sixth ray is well marked, it sends a short branch into it, as in the case of the tubercles on the shaft of some of the long spicules of *Hyalonema*. If the spicule be broken or crushed, the laminated structure so well described by Bowerbank in *Tethya*[*], by Max Schultze in *Hyalonema*[†], and by Claus in *Euplectella*[‡], becomes very apparent, Ten to fifteen siliceous layers can usually be easily detected. Near the point of decussation of the rays these siliceous laminæ seem to become further separated from one another, and the intervening layers of sarcode thicker. When the spicule is burned under the microscope, the black films of carbon which represent the burned sarcode may sometimes actually be seen splitting off separate from the transparent siliceous shells.

The smaller quinqueradiate spicules (Plate LXVIII. fig. 3) resemble the larger in general form; they are, however, much more delicate and flexible, and even more desultory in the distribution of their branches. The stretch of these spicules from tip to tip of two rays of the cross is from 8 to 10^{mm}, and the diameter of each ray not more than ·07 to ·05. Some straight fusiform spicules from ·08 to ·5 in diameter, and from

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[*] A Monograph of the British Spongiadæ, Ray Society, London, 1864.

[†] Die Hyalonemen. Ein Beitrag zur Naturgeschichte der Spongien. Bonn, 1860.

[‡] Ueber *Euplectella aspergillum* (R. Owen). Ein Beitrag zur Naturgeschichte der Kieselschwämme. Marburg und Leipzig, 1868.

10 to 15^{mm} in length, occur in the sponge-substance, but these may, I think, be more properly associated with the spicules of the next group.

2. *The spicules of the "beard."*—It is extremely difficult to isolate the long simple spicules of the beard. The sponges had been rolled about in the mud in the dredge, and the long spicules came up a close tangled mass. One spicule, however, which was not complete, I extricated to the length of 4 decimeters. These spicules are infinitely more delicate, and more flexible and elastic than those of the "glass-rope" of *Hyalonema*, more delicate even than the root-fibres of *Euplectella*. They arise by an extremely fine point in the columns of the sponge-substance (Plate LXX. fig. 1, *a*, *b*). They enlarge gradually, and after passing in bundles through the outer wall of the sponge into the chalk-mud, they maintain nearly the same diameter, from ·1 to 0^{mm}·12, throughout their length. Their structure is not so compact as that of most other spicules. When sharply bent the layers of silica readily separate from one another, and they may be frequently seen with parts of the outer layers broken off (Plate LXVIII. fig. 6). I have never observed more than from ten to twelve layers in the portions which I have examined. The external surface of this spicule is perfectly smooth throughout the greater part of its length. I have not, however, seen a fully developed example complete at the distal extremity.

Along with the bundles of these simple fibres there issue from the interior of the sponge numerous hamate, bihamate, and rarely trihamate spicules (Plate LXVIII. fig. 5, *a–d*, Plate LXX. fig. 1, *a*, *b*). These spicules are from 5 to 10^{mm} in length, from ·02 to ·025 in diameter of the shaft, and the bihamate ones about ·06 across the flukes. They are armed throughout their entire length with longer or shorter, sharper or blunter recurved spines. These spicules are found here and there in the sponge-substance; but usually they run parallel to and are mixed with the sheaves of simple spicules of the beard. They resemble very closely in form the so-called "prehensile spicule" figured by Bowerbank and Claus from the base of *Euplectella*.

Associated with these in the fascicles of spicules of the beard, but much more abundant in the bundles of shorter and more rigid spicules towards the upper portion of the sponge, we find the very beautiful and remarkable spicules, Plate LXVIII. fig. 4.

These spicules are from about 5 to 8^{mm} in length and ·015 in diameter. They are cylindrical, and come to a fine point at each end. All along the shaft minute elliptical or nearly linear depressions are arranged in a close double spiral. The distal end of each depression deepens slightly, so that the markings are somewhat like the scars left by the detachment of leaves. From the distal lip of each depression an extremely delicate spine, visible only with a rather high magnifying power, arises, and runs backwards over the depression, and nearly parallel with the axis of the spicule.

Mixed with the rigid projecting spicules of the upper part of the sponge, tufts of extremely fine siliceous fibres pass out of the sponge-substance. I have found it impossible to isolate one of these fibres (Plate LXVIII. fig. 7) for its entire length, which seems to reach about 20^{mm}. These fibres are glossy, like the ultimate fibres of floss silk. Their diameter is about 0^{mm}·002.

3. *The Spicules of the Sarcode.*—The different forms of spicule which have been hitherto described are stationary, woven into certain definite positions in the texture of the sponge. Besides these, three distinct types of extremely minute spicules are imbedded in the sarcode of the sponge and evidently follow its movements, thus occupying varying positions with reference to the permanent skeleton. The most abundant of these are very minute spicules formed on the hexradiate type, but having, as in the case of the large spicules of the skeleton, only five rays developed. The four secondary branches radiate in the form of a transverse cross, and the fifth projects at right angles, and is feathered with diverging spines curved toward the distal extremity of the ray. These spicules differ in form and size in different parts of the sponge. Those of the outer network (Plate LXVIII. figs. 9 & 9 *a*) are about $0^{mm}\cdot15$ from point to point of opposite rays of the cross. The rays of the cross are stout and rigid, and are frequently slightly roughened with small tubercles. The feathered ray averages about ·17 in length; it is robust, and the spines are numerous and close.

Spicules of this type are very numerous in the sarcode of the oscular network, but they have a somewhat different character. The rays of the cross are slightly longer than in the spicules of the outer network, and are usually smoother and somewhat more delicate. The feathered ray is much longer, averaging about ·22 to $0^{mm}\cdot35$ in length; it is much more delicate, and sometimes slightly curved, and the spines on its surface are smaller, less numerous, and more distant (Plate LXVIII. figs. 10 & 10 *a*).

In the substance of the sponge, these spicules present many varieties in form. Sometimes they are very short and thick, with the barbs of the feathered style numerous and long, and the rays of the cross strongly tubercled (Plate LXVIII. fig. 11); more frequently they are altogether very delicate in their proportions, so much so that the rays of the cross curve irregularly, and the feathered style with its spines entirely lose their rigid and uniform outline (Plate LXVIII. figs. 12, 13, & 14).

The spicules of the sarcode of the second type are not nearly so abundant. They are simple and style-like, slightly fusiform, and come to a fine point at each end; they are about $0^{mm}\cdot2$ in length (Plate LXVIII. figs. 8 & 8 *a*). The shaft is covered with extremely delicate adpressed spines. These spicules somewhat resemble a small portion of one of the long spicules (Plate LXVIII. fig. 4) on a very reduced scale. The last spicule of the sarcode is a small "amphidiscus," a cylindrical spicule $0^{mm}\cdot07$ in length, with, at either end, a crown of six or eight long recurved hooks. These spicules are very numerous, especially so, ranged along the branches of the large spicules of the inner network. They vary slightly in form (Plate LXVIII. figs. 15, 16); but the differences do not seem to be connected with their distribution in the sponge.

The general Arrangement of the parts of the Sponge.

1. *The outer wall.*—The external surface of the sponge is formed of an open network, which presents a very beautiful though somewhat irregular stellate appearance. The centres of the stars, in a band round the middle of the sponge, where the star-like

arrangement is most conspicuous, are about 10^{mm} asunder. In the upper portion of the sponge, towards the lip of the osculum, the stars gradually diminish in size and become less obvious, while close to the lip the stellate arrangement disappears, the meshes become close and irregular, and the tissue looks like fine grey felt. Towards the base of the sponge the network also loses its regularity, but it becomes more coarse and open. The stellate effect of the outer wall is due to a multitude of more or less strongly marked centres, from which an irregular number of rays diverge. The most strongly marked of these centres of radiation form the centres of the prominent stars, but the spaces between these, and among their rays, are full of smaller radiating points from 1 to 2^{mm} distant from one another, and having in every way the same character as those which are more obvious.

The centre of each of the large stars coincides with the point of divergence of the rays of one or two of the large five-rayed spicules (Plate LXVIII. figs. 1, 2, Plate LXIX. figs. 2, 3), and very usually, besides the very large spicules, one or more of the smaller spicules of the same class radiate at the same point. The smaller stars indicate the point of radiation of these smaller spicules alone. The spicules are placed thus: four rays of each spicule spread nearly on the same plane, forming the rays of the star and the supporting framework of the outer wall of the sponge, while the fifth ray plunges down into the substance of the sponge, and forms one of the elements of the remarkable spongy trabeculæ which support the outer casing.

The siliceous rays of one star curve towards and meet the rays of the neighbouring stars, and run along parallel with them (Plate LXIX. fig. 2). All the rays of all the spicules are thickly invested with consistent semitransparent sarcode, which binds these concurrent branches together by an elastic union, and fills up all the angles of the meshes with softly curved viscous masses. This arrangement of the spicules, free, and yet adhering together by long elastic connexions, produces a strong, flexible, and very extensible tissue.

In the more open parts of the outer wall, the meshes between the spicules are from ·5 to 0^{mm}·8 in diameter, and even with a hand-lens these spaces may be seen to be covered by an extremely delicate transparent finer netting. This ultimate network, however, has no siliceous frame, but consists simply of irregularly inosculating threads of sarcode, which rise from the sarcode-sheaths of the branches of the spicules, and stretch, anastomosing irregularly, across the spaces; bounding and defining the inhalent pores of the sponge (Plate LXIX. figs. 2, 3). There can be no doubt from its appearance that the sarcode of this network presents the movement which we find so characteristic of this histological element throughout the group. It is soft, very transparent, and of a pale horn-colour. It contains scattered through it, separate or in groups, minute brownish granules apparently of some form of horny matter, with here and there bodies of more definite outline resembling endoplasts, and two forms of spicules. Where the sarcode covers the branches of the five-rayed spicules and forms the border of the meshes of the larger network, the feathered spicules (Plate LXVIII. fig. 9) are very abundant. The transverse crosses are imbedded in the sarcode and, as it were, stand against the large spicules, while their tree-like branches project outwards, thinly covered with transparent sarcode. Frequently one of these spicules is carried away by the stream of sarcode spreading into the ultimate sarcode-net, and may be seen upon the netting, maintaining its position, with the cross in the network and the brush projecting outwards (Plate LXIX. fig. 3).

The small amphidisci (Plate LXVIII. figs. 15, 16) are less numerous. The position of these bodies in the sarcode appears to be perfectly irregular; they lie in all directions. They are usually found ranged along the rays of the large spicules; but they also often follow the course of the sarcode, and may be seen scattered in the threads of the ultimate network (Plate LXIX. fig. 3).

When the sponge is fresh, with only the mud washed off it, if we look at it in water the spaces between the larger stars seem almost transparent, and show deep cavities penetrating into the substance of the sponge, while beneath the centre of each star an irregular column of sponge-substance rises, spreading somewhat and dividing as it abuts against and supports the star. These supporting columns have a great resemblance in form to the *columnæ carneæ* of the human heart.

Over the whole of the lower third of the surface of the sponge, dense tufts, consisting each of from 20 to 100 of the enormously long simple spicules, portions of which are represented in fig. 6, Plate LXVIII., pass through the centre of the tissue of the trabeculæ in which they originate, through the meshes of the outer wall near the centre of the stars, and spread in all directions in the mud. As each spicule is invested by a sheath of very soft sarcode, the whole of the mud to a distance round the sponge is glairy, as if it were mixed with white of egg. Accompanying the long simple fibres there are usually in each fasciculus from three to eight or ten of the hamate spicules (Plate LXVIII. fig. 5); the bihamate form (figs. 5 & 5 *a*) is much the most common. Some of these spicules end close to the outer network of the sponge (Plate LXX. fig. 1, *a*), while others accompany the bundle of fibres to a distance of several millimeters beyond it. The delicately spined spicule (Plate LXVIII. fig. 4) also occurs in these fasciculi, but comparatively rarely.

The middle zone of the sponge is nearly free from projecting spicules, and the stars are there very regular and distinct; but on the upper third, towards the edge of the osculum, the tissue becomes altogether closer and more confused, the meshes of the siliceous network become smaller, and the sarcode fills them up as a finely perforated membrane. Here, again, bundles of fibres pass outward from the trabeculæ of the sponge; but these are shorter and more rigid than the fibres of the "beard," and project outwards and upwards at a definite angle, forming a kind of coronet round the top of the sponge. Each fasciculus consists of a few (ten or twelve) larger and smaller smooth simple spicules, with one or two bihamate spicules, a number of the spined spicules (Plate LXVIII. fig. 4), and usually a bunch of the silky fibres (Plate LXVIII. fig. 7). These fasciculi, which are about 30^{mm} long on the shoulder of the sponge, gradually shorten towards the osculum, till immediately round its lip there is a close continuous vertical fringe, chiefly of smooth spicules about 10^{mm} high.

2. *The wall of the oscular cavity.*—There can be, I think, no reasonable doubt that the inhalation of water takes place through the pores of the ultimate sarcode network over the whole of the external surface of the sponge, and that the whole of the wall of the internal cylindrical cavity is exhalent, the current finally escaping through the single large osculum. The wall of the inner cavity resembles generally the external wall of the sponge. It is composed of a series of stars formed on the same plan, and by a combination of spicules of the same general form as those of the external stellate membrane. The stars are coarser and more open towards the bottom of the cavity, becoming more obscure above, till at length near the oscular opening the tissue becomes close, irregular, and felted, and at the tip of the osculum it joins the upper portion of the outer wall which has assumed the same character. Under the microscope the network of the oscular cavity (Plate LXIX. figs. 4, 5) differs materially in detail of structure from the outer network. The spicules of the supporting frame are rather smaller, but their distribution is the same, the four secondary rays of each spicule forming an elastic union with the secondary rays of the neighbouring spicules to form the stars, and the fifth ray passing down into trabeculæ of sponge-substance, which, however, are smaller than on the outer surface and less definite in form. The most striking peculiarity in the inner wall is the total absence of the ultimate sarcode network. The siliceous rays are bound together by a thick sheathing of firm sarcode, much more consistent and more loaded with granules than the sarcode of the outer wall; but this sarcode merely covers the spicules and reduces the angular meshes of the network to large irregular oval spaces, by forming deep crescentic accumulations in the angles. Close ranges of the transverse crosses of the long delicate feathered spicules (Plate LXVIII. fig. 10) are imbedded in the sarcode and set against the shafts of the large spicules, and the feathered rays turn towards, and project slightly over, the oval openings, which they thus partially obstruct. The amphidisci are very abundant, imbedded in the sarcode. They are usually more or less regularly ranged in rows, their long axes parallel with the axes of the large spicules.

3. *The Sponge-substance.*—Between the outer and the inner walls the structure is very uniform. A greyish consistent sarcode is hollowed out into rounded channels and communicating spaces of all sizes and of very irregular forms (Plate LXIX. fig. 1, Plate LXX. figs. 1 & 2). These spaces are smaller, and the sponge is therefore more compact towards the inner (oscular) surface, where it has somewhat the appearance in section of a slice of very light loaf-bread. About a centimeter from the outer surface the various channels coalesce and form large sinuses, which surround the columns of sponge already mentioned which support the centres of the large stars. The effect of this arrangement is very peculiar; when the sponge is seen in fluid, the outer network from its almost perfect transparency is entirely lost, and one sees only a globular spongy mass, apparently covered with projecting spongy, broad-based, flat-headed spikes. Towards the oscular network there is also a tendency to the coalescence of the channels, but the sinuses formed are much smaller and less definite in form. The sarcode of the substance of the sponge is firmer and more densely loaded with granules, therefore more opaque, than

that of the outer wall; it is apparently the same as that of the oscular wall. It is supported and its spaces are defined by a very irregular elastic meshing of spicules, which resemble closely the smaller five-rayed spicules of the outer network, only they are somewhat more delicate in their proportions and their rays are longer (Plate LXX. figs. 1, 2). The sarcode contains irregularly scattered through it, but not in very great numbers, the feathered five-rayed spicules, and in this situation they exhibit every variety in form. They are most usually extremely delicate, with curved rays (Plate LXVIII. figs. 12, 13, 14); but some of the stoutest and most rigid spicules (Plate LXVIII. fig. 11) were found associated with these. These feathered spicules are arranged in the substance of the sponge in the same way as in the membranes, the crosses imbedded in the sarcode, and the feathered styles projecting into the sinuses. Amphidisci are much less abundant in the sponge-substance than in either of the walls, but in some places the minute fusiform spicules (Plate LXVIII. figs. 8, 8 *a*) are numerous. Here and there throughout the sponge there is one of the bihamate spicules (Plate LXVIII. fig. 5), and over the lower third of the sponge, and over the upper third, wherever a column or rod of sponge rises to the outer network, a fascicle of siliceous fibres and spicules passes along its axis, becoming free beyond the outer wall of the sponge. In the lower third of the sponge the bundles already described of 20 to 100 long cylindrical fibres originate in the perpendicular columns of sponge-substance. The spicules commence in a fine point, gradually acquiring their full diameter as they approach the surface of the sponge (Plate LXX. fig. 2, *a*); they then pass out into the oozy mud, in which they spread. The layer of sarcode covering these fibres throughout their entire length is equal to about the semidiameter of the fibre. The sarcode is soft and nearly colourless. It contains a few scattered granules and compound granular masses, and apparently no spicules. It is so abundant in the silky beard, that when the fresh sponge is held up it falls from it in flakes and glutinous drops loaded with *Globigerinæ* and chalk-mud. The sarcode of this sponge appears to be perfectly uniform and continuous. There is no trace of its differentiation into cell-like bodies surrounding endoplasts.

Reproduction.

In the specimen of *Holtenia* which was sacrificed in order to investigate the details of internal structure, any indications of the function of reproduction were unfortunately very obscure. Near the base of the sponge, among the granular sarcode bounding the sinuses round the lower part of the exhalent cavity, there were numerous soft, granular, pyriform gemmules. At the particular stage at which they were observed these gemmules were of a bright orange-colour, destitute of spicules, and perfectly uniform in their dense granular structure. Although gemmules and specimens of all ages, of other sponges such as *Tisiphonia* and *Hyalonema*, were detected abundantly in the mud, and even among the fibres of the beard of *Holtenia*, it is singular that neither gemmules nor young specimens of this species were met with.

The Zoological position and affinities of the Genus.

In the 'Annals and Magazine of Natural History' for February 1868, I described a genus of siliceous sponges under the name of *Habrodictyon*, from specimens in the Museum of the Jardin des Plantes. The sponges which are now included in that genus were already well known; but a general external resemblance and want of care in the discrimination of minute characters had previously caused a confusion between one of the species and *Euplectella aspergillum* (Owen), the "Venus's flower-basket" of the Philippines. While studying critically the Paris specimens with the view to the determination of their affinities, I found to my surprise that a number of sponges from very different parts of the world, to which had only been attributed hitherto the common character of extreme beauty and rarity, were associated by structural and histological peculiarities sufficiently marked to distinguish them as a group from all the recognized orders of the Class PORIFERA. For these sponges I accordingly proposed to establish a new order, for which I suggested the name (Porifera) VITREA. It is remarkable that nearly all the genera and species of sponges which we met with in the deep water of the warm area of the Atlantic were referable to the new order, and from their having been found living and *in situ*, the new forms threw a flood of light upon the relation and mode of occurrence of the group.

In defining the position of the vitreous sponges, I have employed the classification proposed by Dr. OSCAR SCHMIDT in his valuable work on the Sponges of the Adriatic*. I have, however, thought it necessary to propose certain slight modifications in his system, and the large number of additional genera which I have now had an opportunity of examining have led me to alter slightly my view of the sequence and affinities of the orders. The following outline of a classification of sponges, slightly modified from that of Dr. OSCAR SCHMIDT, will serve to indicate the position which in the present state of information I should be inclined to assign to the vitreous sponges.

Class PORIFERA, Grant.

Subclass I. (Porifera) CALCAREA, Bowerbank. "Skeleton composed of calcareous spicules which are generally three-rayed stellate" (Gray), equivalent to Dr. O. SCHMIDT'S first family. Examples: *Grantia*, *Sycon*.

Sub-class II. (Porifera) SILICEA, Gray. "Sponges provided with a siliceous or horny skeleton, or with a horny skeleton strengthened with siliceous spicules."

Order I. (P. Silicea) VITREA, Wyville Thomson. Sarcode usually soft, containing but little formed horny matter in the form of minute granules. The skeleton consists entirely of siliceous spicules, either separate (in fascicles or scattered) or soldered together and combined into a continuous siliceous network. The sarcode contains small free spicules, different in character from the spicules of the skeleton, and frequently of complicated forms. In the typical sponges of the order all the spicules whether of the skeleton or of the sarcode, may be referred to the hexradiate type. Examples: *Holtenia*, *Hyalonema*, *Dactylocalyx*.

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* Die Spongien des Adriatischen Meeres. Leipzig, 1862 (and Supplements).

Order II. (P. Silicea) RADIANTIA, Wyville Thomson (=Corticata, Oscar Schmidt, in part.) Globular, tuberous, or branched sponges, supported by regular radiating sheaves of long siliceous spicules, and invested with a more or less dense cortical layer, often containing spicules of special and characteristic forms.

Suborder I. (Radiantia) CORTICATA (=Corticata, Oscar Schmidt). Cortical layer dense and well defined. Examples: *Tethya*, *Geodia*, *Placospongia*.

Suborder II. (Radiantia) LEPTOPHLEA (Wyville Thomson). Cortical layer consisting of a thin, almost membranous, sheet of soft sarcode. Examples: *Tisiphonia*, n. g., *Stylocordyla*, n. g.

Order III. (P. Silicea) HALICHONDRIDA. Sponges tuberous, branching, cup-shaped, irregular, or incrusting; without any definite cortical layer. The sarcode is abundant, consistent, and in all cases is supported by a considerable amount of horny matter, which is fibrous, granular, and diffused, or in the form of more or less distinct membranous expansions. The sponge frequently contains an abundance of siliceous spicules variously arranged.

Suborder I. (Halichondrida) HALICHONDRINA (Lieberkühn). Sarcode abundant, usually consistent. The horny matter is granular or membranous, but is never in the form of a network of solid horny fibres. The skeleton consists mainly of siliceous spicules, which are usually essentially of the same form in all parts of the sponge. In one family, the ESPERIADÆ, the sarcode is soft, and the spicules are of two distinct types. Examples: *Halichondria*, *Spongilla*, *Esperia*.

Suborder II. (Halichondrida) GUMMININA (=Gummineæ, Oscar Schmidt). Sponge-substance compact; skeleton of fine densely interwoven horny fibres. Siliceous spicules in some of the genera. Examples: *Gummina*, *Corticium*.

Suborder III. (Halichondrida) SPONGINA (Lieberkühn). Skeleton an elastic wide-meshed network of anastomosing horny fibres, frequently containing foreign bodies, such as grains of sand and spicules of other sponges, and occasionally having siliceous spicules developed within them, but never associated with free siliceous spicules in the sponge-mass. Examples: *Spongia*, *Chalina*, *Dysidea*.

Order IV. (P. Silicea) ARENOSA (=Arenospongia, Gray).—" Sponge consisting of a disk of agglutinated sand, with a series of diverging spicules on the circumference of the disk, and with a pencil of similar spicules at the mouth of the oscules on the upper surface of the disk" (Gray, Proc. Zool. Soc. May 9th, 1867). Example: *Xenospongia*.

Order V. (P. Silicea) HALISARCINA (Lieberkühn). Sponge destitute of either siliceous or horny support. Example: *Halisarca*.

The following genera and species may, I believe, be referred with certainty to the Order PORIFERA VITREA:—

- Genus 1. Euplectella, Owen.
  - *E. aspergillum*, Owen.
- Genus 2. Habrodictyon, Wyville Thomson.
  - *H. speciosum*, Quoy & Gaimard (sp.).
  - *H. corbicula*, Valenciennes (sp.).
- Genus 3. Aphrocallistes, Gray.
  - *A. beatrix*, Gray.
  - *A. bocagei*, Wright, MSS.
- Genus 4. Dactylocalyx, Stutchbury.
  - *D. pumicea*, Stutchbury.
  - *D. subglobosa*, Gray.
  - *D. Prattii*, Bowerbank.
  - *D. callocyathes*, Gray (sp.).
  - *D. azorica*, Gray (sp.).
  - *D.* (?) *torva*, Duchassaing and Michelotti (sp.).
- Genus 5. Farrea, Bowerbank.
  - *F. occa*, Bowerbank.
- Genus 6. Holtenia, Wyville Thomson.
  - *H. Carpenteri*, Wyv. Thomson.
- Genus 7. Hyalonema, Gray (in part).
  - *H. Sieboldi*, Gray.
  - [*H. lusitanicum*, Gray.
  - *H. Loveni* (sp. nov.).
- Genus 8. Adrasta, (gen. nov.).
  - *A. infundibulum* (sp. nov.)*.

The characters which the vitreous sponges possess in common are sufficient to combine them into a very natural order. In all, the sarcode is in comparatively small quantity, and spreads in a thin translucent layer over the spicules or network of a highly developed siliceous skeleton. In all the known genera all the spicules, whether of the skeleton or of the sarcode, are modifications of the hexradiate stellate type. In *Euplectella*, *Aphrocallistes*, *Dactylocalyx*, and *Farrea*, large hexradiate spicules are more or less completely soldered together, and form a continuous anastomosing network. In *Habrodictyon*, *Holtenia*, *Hyalonema*, and *Adrasta*, the skeleton is composed entirely of separate spicules, either distinctly hexradiate or quinqueradiate, or triradiate, or simple, by the suppression of one or more of their secondary branches. The sarcode of the inhalent and exhalent surfaces, and of the substance of the sponges, always contains scattered through it, numerous very minute spicules of very characteristic forms. In *Aphrocallistes*, one of the most abundant forms of these spicules of the sarcode is a regular six-rayed star with the principal axis longer than the transverse rays and one half of it feathered. In *Holtenia*, *Adrasta*, and *Hyalonema*, a spicule of the same type is common, but one half of the axis is undeveloped, so that the spicule has become quinqueradiate. In *Euplectella*, *Habrodictyon*, and *Dactylocalyx*, there are several modifications of a very complicated and beautiful spicule, the floricomo-hexradiate of Bowerbank. The most remarkable spicule, the double grapnel (Plate LXVIII. fig. 15), seems to be the most widely diffused of all in the order. It varies little in form in *Hyalonema*, *Holtenia*, and *Adrasta*, in all of which it is abundant; and modifications differing only in the number, the curve, or the proportions of the flukes, or in the relative length of the stem, have been found in almost all the soundings from the deep sea, indicating a multitude of yet to be discovered species of vitreous sponges.

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* Since this list was written a number of additional vitreous sponges have been described by Dr. Bowerbank and by Professor Barboza de Bocage; and several new forms have been added from the rich collections made by M. de Pourtales in the Strait of Florida in connexion with the American Coast Survey, and by the Naturalists in charge of the 'Porcupine' deep-sea dredging expedition. The sponges collected by M. de Pourtales are in the hands of Professor Oscar Schmidt for description; and a report on those procured by the English expedition is in course of preparation by the writer.

Our knowledge is not as yet sufficiently extensive to enable us to form a definite opinion as to the affinities and sequence of the genera of this order. *Holtenia* is undoubtedly very closely allied in general structure and in the form of its spicules to *Hyalonema*, the principal differences between them being in the general form of the sponge, and in the character and arrangement of the long fibres of the "root."

Nor is it yet possible to define with anything like certainty the position of the order in the series of the PORIFERA. There is something in the wonderful complexity of design and profusion of ornament in the siliceous skeleton which recalls the RADIOLARIA, and in some cases even the special forms of the spicules are repeated in the two groups. (Compare pl. 12, fig. 1, pl. 17, fig. 4, pl. 18, fig. 15, pl. 21, fig. 7, pl. 32, figs. 10, 11, pl. 33, figs. 6, 7, &c. of HAECKEL'S 'Die Radiolarien.') The sarcode is certainly more mobile, less loaded with granular matter, and more transparent than in most of the other groups of sponges. For sarcode in this condition one would be inclined to anticipate a somewhat higher form of vital activity. Under an impression that it is through this order that the sponges pass into the RADIOLARIA, I have placed the Porifera Vitrea at the head of the series of siliceous sponges, beginning with those genera in which the siliceous structures are most varied, and the sarcode least consistent. The typical vitreous sponges appear to approach the RADIANTIA through such forms as *Tisiphonia* and *Stelletta*, and the HALICHONDRIDA, probably through *Esperia*.

I believe, however, that it is not to the well-known orders of recent sponges inhabiting shallow water that the vitreous sponges are most nearly allied. A very remarkable group of fossils, the Ventriculites, are highly characteristic of the cretaceous formation. These are tubular or vase-shaped bodies, presenting a great diversity of graceful form and elegant sculpture. The late Mr. TOULMIN SMITH devoted much time and skill to their investigation, and came to the conclusion that they were POLYZOA. This view of their position, however, presents many difficulties, and the study of Mr. TOULMIN SMITH'S careful drawings and descriptions is in itself sufficient to suggest other affinities.

The general resemblance between some of the Ventriculites and *Euplectella* is very striking, while others approach the less regular form of *Aphrocallistes*, and this resemblance extends even to the details of the structure of the network of the wall. The striking difficulty is, that while the skeletons of the vitreous sponges to which the complicated network of delicate tubes forming the wall of the Ventriculites must be compared, are siliceous; as a rule no silica enters into the structure of the Ventriculites. The tubes are empty or filled with loose particles of carbonate of lime, coloured by peroxide of iron. Recent observations have shown that in very many particulars the modern deposits in the "warm area" of the Atlantic resemble most closely the deposits of the cretaceous seas; and, as has already been stated by Dr. CARPENTER, many animal forms identical with chalk fossils, or so nearly allied to them as to justify the assumption of modification by variation, or of direct descent, are now being imbedded in the Atlantic chalk-mud. So remarkable are the resemblances between the two formations and their respective faunæ, that for this and for other reasons which will be fully discussed elsewhere, the conviction has been forced upon my colleague Dr. CARPENTER and myself, that the deposit of "chalk-mud" at present taking place in the Atlantic is continuous with the deposit of chalk-mud of the cretaceous period, and that the margins and the shallower portions only of the cretaceous sea-bed have been elevated into dry land*.

One great difference, however, exists between the modern chalk-mud and the ancient chalk. The modern chalk-mud from all deep-sea soundings is full of delicate siliceous organisms, Diatoms, Radiolarians, and Sponges, while the chalk is almost devoid of diffused silica. From the circumstances under which silica occurs in the chalk, forming bands of flint, masses of amorphous silica which have evidently taken the form of any cavities or moulds occurring in the beds, we have been led to believe that the silica existed originally in the form of diffused organisms in the chalk of the cretaceous period as in the modern chalk, and that it was afterwards dissolved out; and filtered through the chalk, and retained in a colloid state in the cavities, by a process of dialysis. If this view be correct, we should be inclined to regard the Ventriculites in their ordinary state of preservation, as the moulds of delicate siliceous fabrics either identical with or very closely allied to the recent vitreous sponges; from which the silica has been removed, its place being occupied by stained carbonate of lime.

The habitat and the conditions of life of the Vitreous Sponges.

The geographical distribution of the order seems to be very wide. *Euplectella* is found in the Philippine Archipelago, and *Habrodictyon* off the Isle of Bourbon. *Hyalonema* is abundant in the seas of Japan, and has been procured in deep water off the coast of Portugal, near the north coast of Scotland, and at Santa Cruz. *Aphrocallistes Bocagei* was procured at the Cape de Verd Islands, and *Dactylocalyx* is abundant in the seas of the Antilles, and has been brought from the Azores and from Madeira. With the exception of *Dactylocalyx*, which, so far as I am aware, has hitherto been only found scattered like pieces of pumice on the sea-shore, but which appears from its form to grow attached to something, the habitat of the whole vitreous order of sponges is oozy calcareous mud. Soundings over a great part of the North Atlantic, embracing the Telegraph Plateau and the greater part of the vast region swept by the Gulf-stream, and also over a large portion of the Pacific, have shown that an important calcareous deposit is taking place throughout the whole of the warmer regions of the ocean. This deposit, so far as it has hitherto been investigated, presents a very uniform character. It consists mainly of fine particles of carbonate of lime, and the sounding-apparatus always brings up a considerable proportion of the fresh shells of *Globigerina* with smaller numbers of the shells of other Rhizopods. The sounding-lead sinks several feet into this fine deposit; and it seems that the deeper part of the mud consists chiefly of an amorphous calcareous paste, produced by the disintegration of the Rhizopod shells, partly by pressure and the decomposition of the cementing animal matter, and partly by the solution in the sea-water of a portion of the carbonate of lime in the presence of disengaged carbonic acid; while the surface-layer consists almost entirely of living Rhizopods, principally *Globigerinæ*. The sponges live buried in the upper layer of the mud. They are frequently so coloured and saturated with the chalk-mud up to a certain point, that one can tell at once to what extent they have been immersed. From the low density of the diffused protoplasm of the living forms, the condition of fine division of the carbonate of lime, the slightly increased density of the water, and the stillness, the transition from a semifluid to a gradually solidifying mud must be very gradual. There are two ways in which the bodies of the sponges may support themselves and maintain their position in this treacherous medium, and both seem to be adopted by different genera. *Holtenia* stretches out an unlimited maze of light spreading fibres, thus increasing its surface indefinitely without adding greatly to its weight. *Hyalonema* sends down perpendicularly a coil of strong spicules which gradually spread till they reach a stratum firm enough to give them anchorage.

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* "Preliminary Report, by Dr. WILLIAM B. CARPENTER, V.P.R.S., of Dredging Operations in the Seas to the North of the British Islands, carried on in Her Majesty's Steam-vessel 'Lightning,' by Dr. CARPENTER and Dr. WYVILLE THOMSON," Proceedings of the Royal Society, vol. xvii.

The question naturally arises, how is this enormously extended layer of animal life nourished? The dredge brings up no plants from great depths; and although from the fact that many of the higher invertebrates which are associated with the sponges and rhizopods have eyes and are brightly coloured, it seems probable that a certain amount of light penetrates to the abysses; it certainly does not appear to be in the form which is necessary for the decomposition of binary compounds by plants. To meet this difficulty it has been suggested that the PROTOZOA, the PROTISTA of HAECKEL, may have the power, though in a minor degree, of assimilating the elements of water, carbonic acid, and ammonia*. It has appeared to us that the nutrition of this animal layer may be explained more simply, and that it may even be found to be a necessary complement to the received doctrine of the "balance of organic nature." All sea-water contains a certain quantity of organic matter in solution, or in a state of minute molecular subdivision. This organic matter is derived from the life (by exosmosis) and the death (by decomposition) of a fringe of sea-weeds round all coasts; of a superficial layer of diatoms and allied forms covering all the warmer seas; in the Atlantic of a meadow of sea-weed two millions of square miles in extent; from the life and death of myriads of pelagic and littoral animals; and from rivers, especially the great rivers of the tropics, whose water is constantly loaded with organic matter. These ternary and higher compounds already gained from the inorganic kingdom, and which would otherwise accumulate indefinitely, might indeed be dissipated by gradual decomposition, but it seems more consistent with the economy of nature that a considerable portion at all events of the organic matter should pass through the complete cycle of organic life, in the ocean as well as on the land.

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* Dr. G. C. WALLICH, 'The North-Atlantic Sea-bed.' Part 2. The Bathymetrical limit of Animal life in the Ocean, p. 131.

The Monthly Microscopic Journal, January 1, 1869, p. 32.

The PROTOZOA, to which subkingdom the mass of animal life, Rhizopods and Sponges, occupying the depths of the sea may be referred, absorb through their whole surface matter, organic or inorganic, in solution or in a state of molecular subdivision. They are therefore specially adapted to the task of freeing the sea-water of its excess of organic matter; at the same time they reduce to a solid form the dissolved carbonate of lime and silica, and slowly through countless ages pile up the fine calcareous sediment which forms the amorphous matrix of beds of limestone, and accumulate the colloid silica which yields the cherts and flints.

The higher invertebrate animal forms which are associated with the Protozoa at great depths, though comparatively scarce and of small size, represent nearly equally all the leading types of structure. There is, however, no difficulty as to the nutrition of these higher animals. They simply feed upon the Protozoa, and the conditions of temperature, of light, and of the aëration of the water are such as to sustain them in life, although in a somewhat dwarfed and imperfectly developed condition.

In the present communication I have only referred to these considerations involving the general conditions of the depths of the sea, so far as appeared to be absolutely necessary for the illustration of the economy of the genus *Holtenia*. Those conditions will be fully discussed by Dr. CARPENTER and myself in our general report on the investigation.

ADDENDUM.

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On the 21st July, 1869, during the Deep-sea Exploring Cruise of H. M. S. 'Porcupine,' the dredge brought up from a depth of 725 fathoms, Lat. 48° 50′ N., Long. 11° 09′ W., off the mouth of the English Channel, several young specimens of *Holtenia Carpenteri*, with the sponge-body from 2 to 200^{mm} in length. The youngest specimens (Plate LXXI. fig. 1) seemed only to have passed out of the condition of gemmules. The contour of these young sponges is more elongated and pyriform than that of mature examples. The external wall consists of a single series of quinqueradiate spicules, much more regular in form than those of the larger sponges; the four secondary branches decussate nearly at right angles, and the fifth branch is quite straight, and plunges into the sponge nearly vertically (Plate LXXI. fig. 8, which represents one of the spicules of the outer membrane of the sponge, fig. 2). It seems to be afterwards, during the growth of the sponge, that the spicules while enlarging greatly, become distorted and irregular in the distribution of their rays. The smaller spicules of the sponge-body (Plate LXXI. fig. 11) are likewise more regular, and a few examples were met with of the very regular hexradiate spicule (Plate LXXI. fig. 10), a form which is very abundant in HYALONEMA.

In the youngest sponges the stellate arrangement of the outer membrane is not yet perceptible; the surface is merely divided by the spreading rays of single spicules into rudely square meshes (Plate LXXI. fig. 1); very early, however, the stars begin to appear by the accumulation and radiation of several of the large spicules at one point, where they send all their azygous branches dipping into the sponge in a sheaf (Plate LXXI. fig. 3 *a*). The osculum is very distinct at the summit of the sponge from the first, and very early the coronet of upright spicules may be detected rising round its edge. The oscular cavity is at first somewhat irregular in form, and its walls are very imperfect and open. The spicules of the sarcode of the young sponges do not differ in any essential particular, either in form or position, from those of the adult. The characteristic spicules (Plate LXXI. figs. 13 & 15) occur ranged as in the adult along the shafts and branches of the spicules of the outer and oscular walls. The 'amphidisci' also occur, although not in large numbers. These latter did not seem even to have attained their full numerical proportion in a young *Holtenia* three centimeters long which we dredged later in the season off the North of Scotland. One example is figured (Plate LXXI. fig. 15) of a regular hexradiate feathered spicule from the young sponge (Plate LXXI. fig. 3). This is the characteristic spicule of the sarcode of the netted lid of the genus APHROCALLISTES. It might easily occur as an abnormal spicule in *Holtenia*, simply by the symmetrical development of the other half of the shaft of the ordinary feathered spicule of the outer wall (Plate LXXI. fig. 14); but as a species of APHROCALLISTES was common on the same ground, I am by no means sure that one of its spicules may not have got accidentally entangled in the young HOLTENIA.

All the young *Holteniæ* in their earlier stages have a beard consisting of a single pencil of long spicules passing out together through one of the meshes of the outer wall, in the centre of the narrow (inferior) end of the sponge, exactly opposite the centre of the osculum. The fascicle consists of from twenty to thirty of the long simple spicules and four or five of the bihamate spined spicules (Plate LXXI. fig. 9). At this stage it is difficult to distinguish *Holtenia*, except under the microscope by the form of the spicules, from *Hyalonema* of the same age. *Hyalonema* seems to retain this embryonic character through life, the single original sheaf becoming enormously enlarged, while in *Holtenia* the fascicles are indefinitely multiplied. Young *Holteniæ* from 20 to 30^{mm} in length are hispid with the finely serrated spicules (Plate LXXI, fig. 19) which pass out singly and quite irregularly through the meshes of the wall. The sponge-substance is very loose, and the cavities, which afterwards become symmetrical, are at first irregular and very large in proportion to the size of the sponge. The long spicules of the beard fascicle do not remain in a single sheaf within the sponge-body, but spread round the osculum, and appear to rise from different parts of the sponge-substance, even close to the sponge-wall. They only approach to pass out of the sponge together.

On the 16th of August, and on the 7th of September, 1869, Her Majesty's Ship 'Porcupine' visited almost precisely the same spot where the specimens of *Holtenia* were dredged in 1868 from the 'Lightning.' With finer weather and much better appliances we were this year much more successful; we got abundance of specimens of *Holtenia Carpenteri*, of various sizes and ages, and many examples of the other vitreous sponges with which it is associated. All the mature specimens, however, seemed to be in precisely the same condition as those procured last year, and threw no additional light upon the structure or physiology of the species. During the past year one or two additional species of the genus *Holtenia* have been observed by Professor Oscar Schmidt, along with several other sponges of the vitreous group, among the sponges dredged by M. de Pourtales in the Strait of Florida. These species are not yet described.

Description of the Plates.

PLATE LXVII.

Holtenia Carpenteri, new genus and species. Natural size.

PLATE LXVIII.

Figs. 1, 2. The large quinqueradiate spicules of the outer network. × 40.

Fig. 3. One of the smaller quinqueradiate spicules, from the network of the oscular cavity. × 40.

Fig. 4. A spiny spicule from the margin of the osculum. × 150.

Figs. 5, 5 *a* to 5 *d*. Different forms of the hamate spicules from the fascicles of the "beard." × 150.

Fig. 6. A small portion of one of the long simple spicules of the "beard." × 150.

Fig. 7. A portion of one of the delicate silky fibres from the neighbourhood of the osculum. × 250.

Figs. 8, 8 *a*. Fusiform "spicules of the sarcode," from the inner part of the sponge-substance. × 250.

Figs. 9, 9 *a*. Feathered "spicule of the sarcode," from the network of the outer wall. × 200.

Figs. 10, 10 *a*. Spicules of the same type from the wall of the oscular cavity. × 200.

Figs. 11, 12, 13, 14. Spicules of the same type from different parts of the sponge-substance. × 250.

Figs. 15, 16. "Amphidisci." × 600.

PLATE LXIX.

Fig. 1. Vertical section of the sponge, showing the oscular cavity and the general arrangement of the sponge-substance. Natural size.

Fig. 2. A portion of the cuter wall, showing the stellate arrangement of the siliceous spicules, and the ultimate sarcode network with the inhalent pores. × 25.

Fig. 3. A small part of the same preparation. × 100.

Fig. 4. A portion of the wall of the oscular cavity. × 40.

Fig. 5. A part of the same. × 200.

PLATE LXX.

Fig. 1. A section of one of the trabeculæ of the substance of the sponge, showing the origin of two of the fascicles of spicules of the beard, which pass through the outer wall of the sponge at *a* and *b*. ×20.

Fig. 2. Vertical section of the sponge-substance from the upper part of the sponge, near the edge of the osculum. ×20.

PLATE LXXI.

Fig. 1. HOLTENIA CARPENTERI, young. ×50.

Fig. 2. HOLTENIA CARPENTERI, somewhat more advanced. ×5.

Fig. 3. Section through the specimen, fig. 2. ×5.

Fig. 4. Another specimen. ×5.

Fig. 5. Oscular surface of the same, seen from above. ×5.

Fig. 6. A somewhat younger specimen. ×5.

Fig. 7. One of the spicules of the outer wall of the sponge, fig. 3. ×50.

Fig. 8. Bihamate spicule of the beard. ×100.

Fig. 9. Regular six-rayed spicule from the substance of the sponge, fig. 2. ×100.

Fig. 10. Nearly similar spicule from the same sponge. ×100.

Fig. 11. Small serrated spicule of the sarcode. ×100.

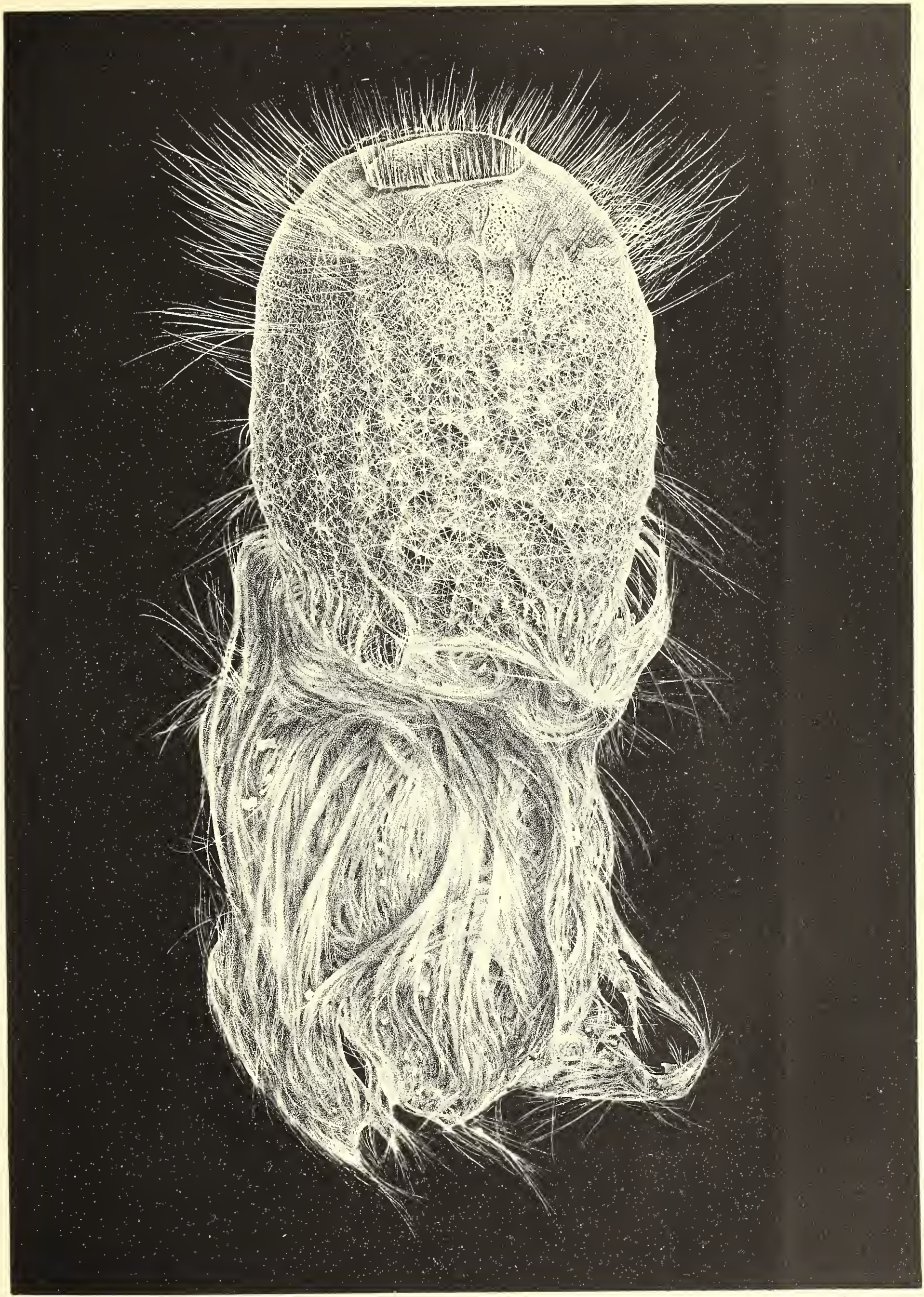
Figs. 12, 13. Feathered spicules of the sarcode from the outer wall. ×100.

Fig. 14. Hexradiate feathered spicule, possibly from the netted lid of APHROCALLISTES, and accidentally entangled in the young *Holtenia* (fig. 2). ×100.

Figs. 15, 16, 17. "Amphidisci." ×100.

Fig. 18. Serrated projecting spicule from the surface of the sponge. ×100.

Phil. Trans. MDCCCLXIX. Plate LXVII.



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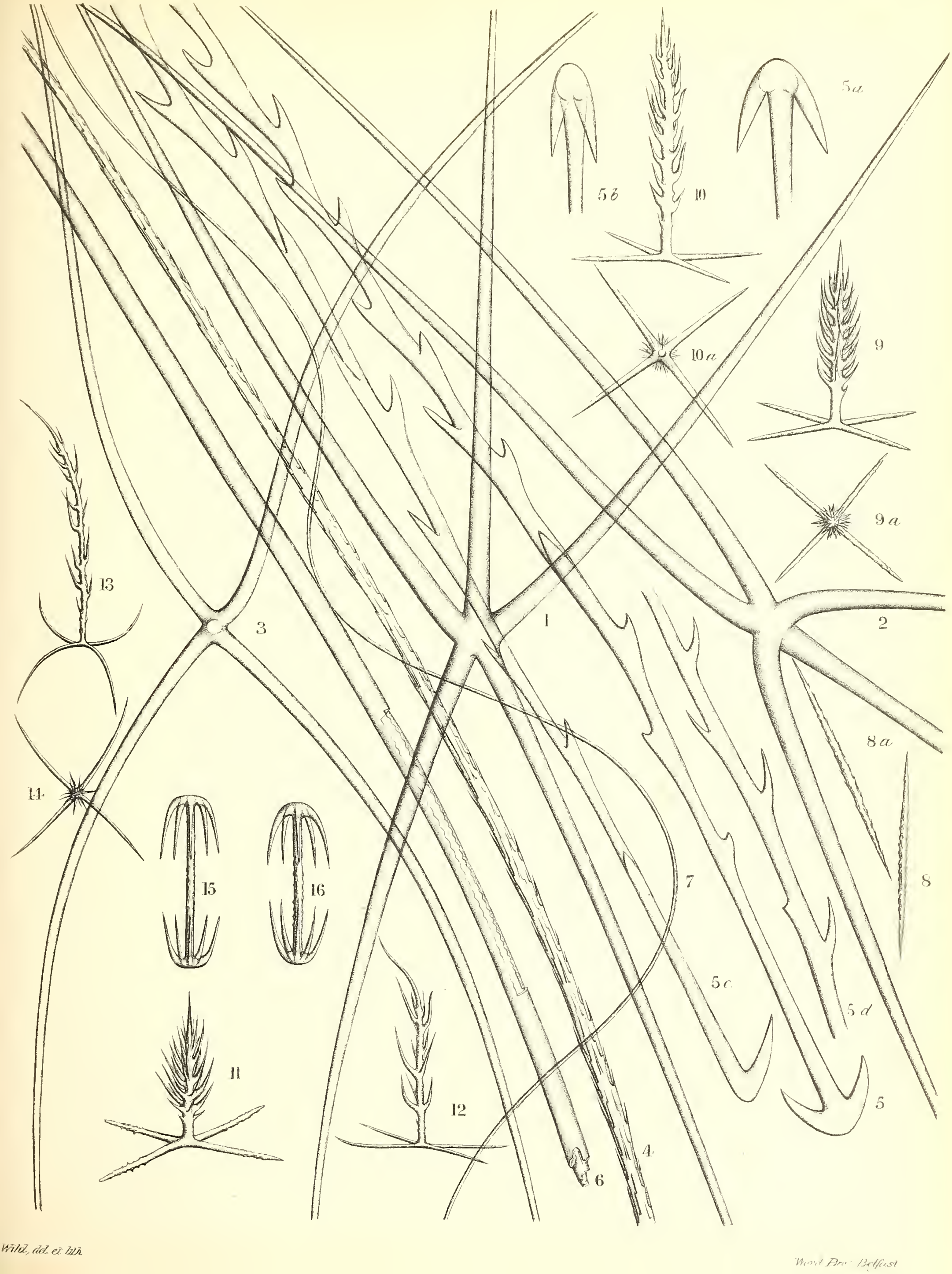

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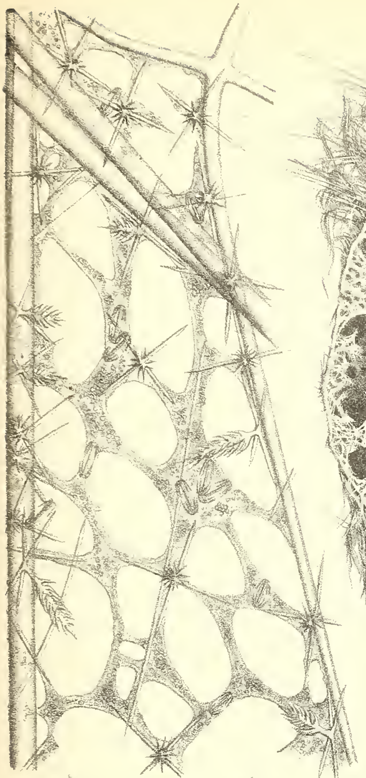

Fig 3

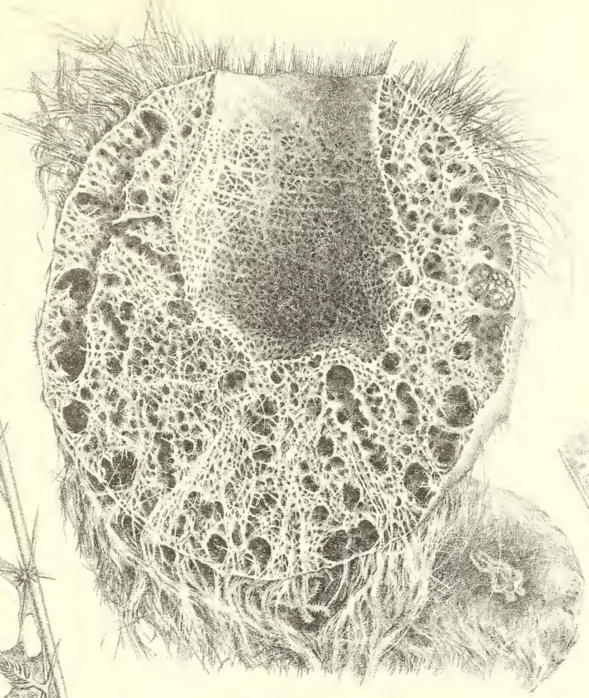

Fig 1

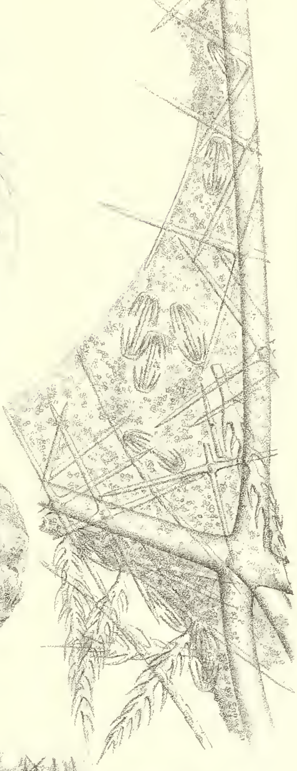

Fig 5

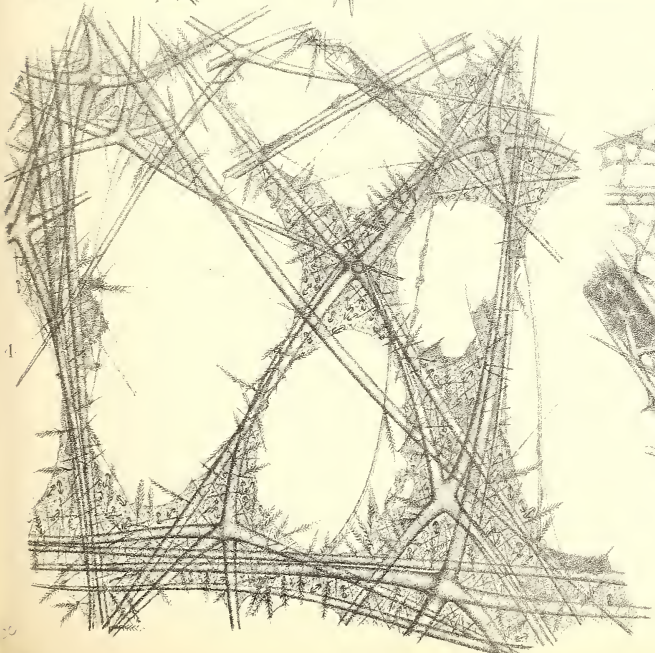

Fig 4

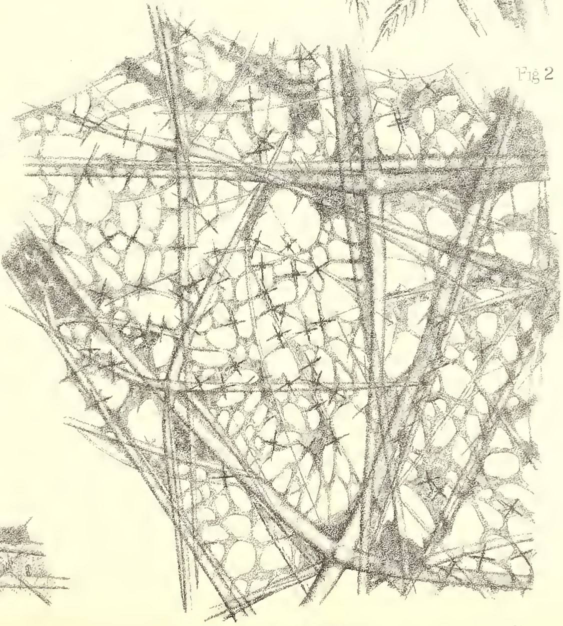

Fig 2

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Fig 2

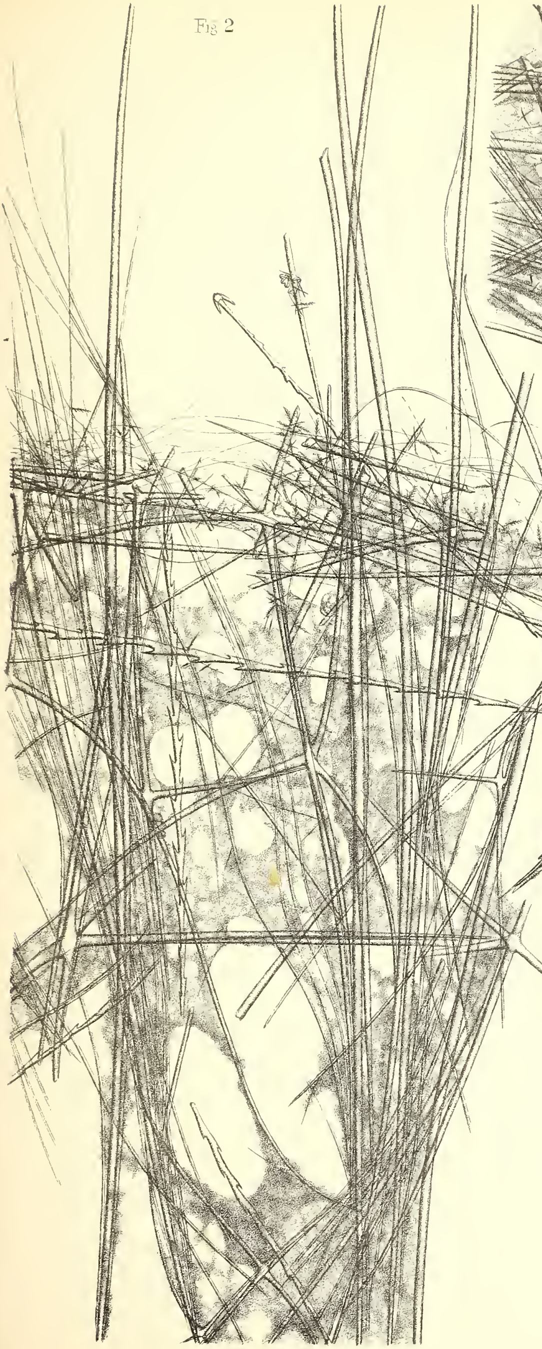
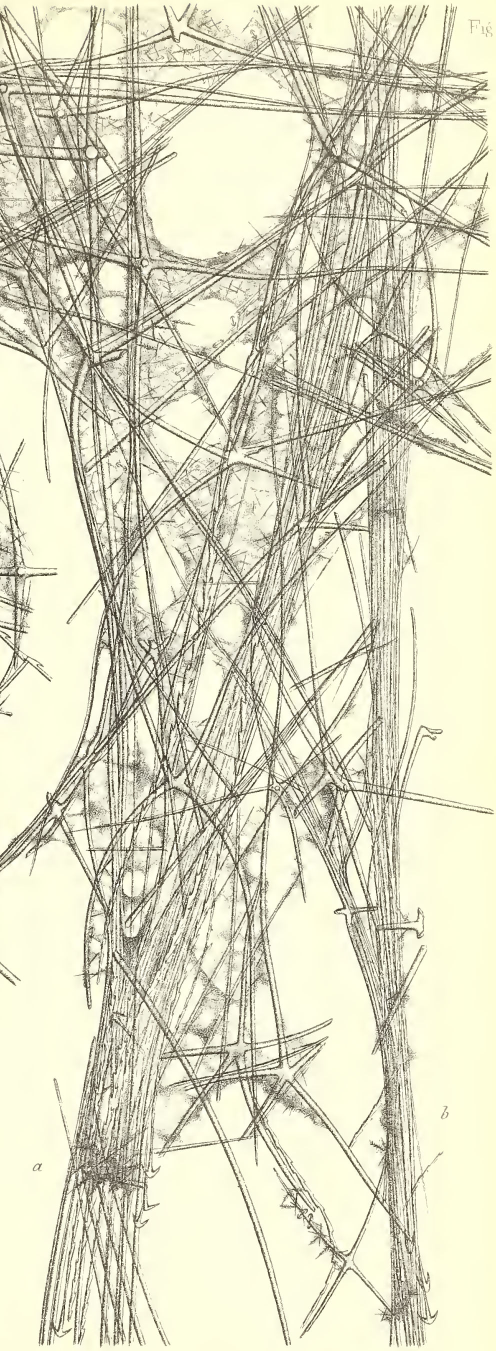


Fig 1



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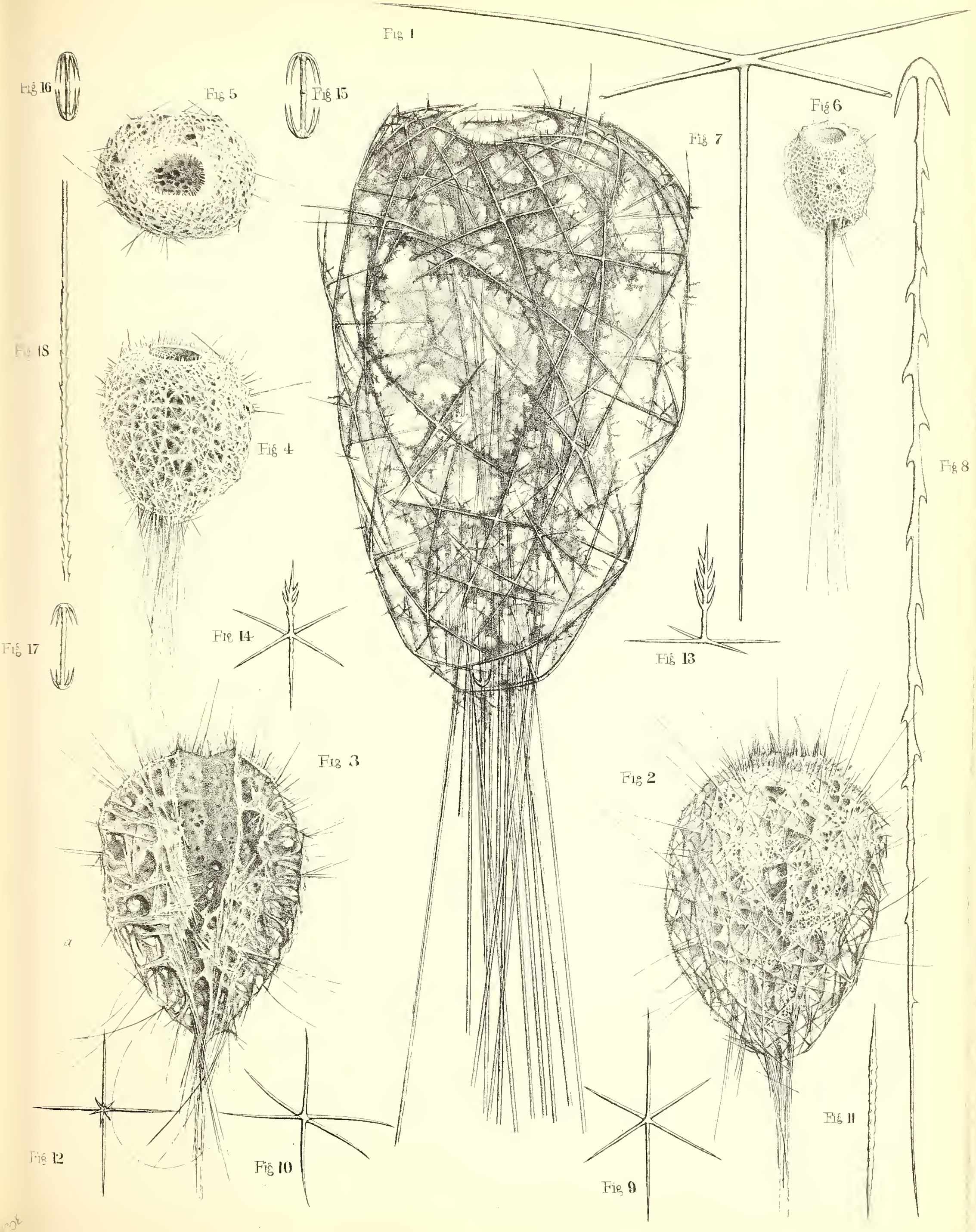

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XXVIII. *Description of* Parkeria *and* Loftusia, *two gigantic types of Arenaceous Foraminifera. By* William B. Carpenter, *M.D., V.P.R.S., and* Henry B. Brady, *F.L.S.*

Received March 18,—Read April 22, 1869.

Introduction.

In the "Concluding Remarks" appended to Part II. of my "Researches on the Foraminifera" (Philosophical Transactions for 1856, p. 565), I pointed out that the System of Classification of that group which had been erected by M. D'Orbigny on the exclusive basis of *plan of growth*, was inconsistent with the facts disclosed by a careful study of the organization of the five typical Genera described in my first and second Memoirs: since it had the effect of bringing together Genera whose strongly marked physiological differences required that they should be separated by the widest possible interval; whilst it ranked under different Orders generic types which exhibit the closest physiological relationship. And I then laid it down as a fundamental principle, "that physiological conformity in the condition of each individual segment, as indicated by the *structure of its shelly investment*, is a character of primary importance; whilst the *plan of growth*, that is, the mode of increase in the number of chambers, is a character of subordinate importance." And in the "Concluding Summary" appended to Part IV. (Philosophical Transactions, 1860, p. 569), I further expanded this doctrine, by showing that all the types which I had described might be ranged in two parallel Series: one of them characterized by that peculiar texture of the Shell which had been appropriately designated *Porcellanous* by Professor W. C. Williamson*; whilst the shell-substance of the other has the texture which had been described by the same excellent observer, with equal appropriateness, as *Hyaline* or *Vitreous*. A third type of Shell-structure had been noticed by Professor W. C. Williamson (*loc. cit.*) under the designation *Arenaceous*; the shell being mainly formed, not by a calcareous exudation from the sarcode-body of the animal, but by the aggregation of particles of sand obtained from without, the cement by which these are attached together being all that the animal supplies. These differences in the character of the Shell were regarded by Professor W. as indicative of "physiological differences in the living sarcode, or secreting animal substance, that have at least a *specific* value:" but while expressing (p. xix) a strong opinion as to the unphilosophical nature of M. D'Orbigny's System, he did not propose any substitute for it; and contented himself with ranking *porcellanous*, *vitreous*, and *arenaceous* shells that correspond in general form, as distinct Species of the same genus.

The Arenaceous type having been made an object of special study by Messrs. Parker and T. Rupert Jones, they were led to recognize it as having the same fundamental value in a systematic point of view as the *Vitreous* and *Porcellanous* types; and it was in accordance with their representations, that, in my "Introduction to the Study of the Foraminifera" (1862), this type was recognized as characterizing a *third* great Primary Division of the group. It was pointed out, however, that "to separate all the *Foraminifera* that form Arenaceous shells from those of the Porcellanous and Hyaline types, to which many of them obviously bear the closest affinity, would be a violation of the first principles of a natural arrangement; and yet we shall find that there are certain generic types in which the sandy texture is a character of great systematic importance." In certain genera, alike of the Porcellanous and of the Vitreous series, the *surface* of the true shell is often covered with an arenaceous incrustation; but this is a character that does not justify even specific differentiation. It is only when the *whole thickness* of the 'test' is composed of agglutinated sand-grains, and when "certain assemblages of forms, constituting well-marked generic types, can be uniformly characterized by the possession of Arenaceous shells,—as is the case with *Trochammina*, *Lituola*, and *Valvulina*,"—that we are enabled to recognize the distinctive value of this peculiarity, as marking "a fixed and decided physiological character, the occurrence of which elsewhere is only occasional or incomplete." It was further pointed out that the absence of pseudopodial pores in the shells of this group shows their affinity to be rather with the *Porcellanous* than with the *Vitreous* series, notwithstanding the very close resemblance which some of them present to particular types of the latter (*op. cit.*, pp. 46–48).

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* "On the Recent Foraminifera of Great Britain," Introduction, p. xi.

At the time that the Chapter "On the Principles of Classification" in the Treatise just cited was passing through the press, I learned with great satisfaction that Professor Reuss of Vienna,—the highest Continental authority upon this group,—had fully accepted the doctrine laid down in my previous Memoirs, that the composition and intimate structure of the Shell are characters of primary importance in Classification, and that little value in comparison is to be attached to Plan of Growth; and that he had communicated to the Imperial Academy of Vienna a Systematic Arrangement based on these principles, essentially corresponding with that which I had myself worked out with the assistance of my able coadjutors (Messrs. W. K. Parker and T. Rupert Jones), —except in the retention of the distinction between the *Monothalamia* and the *Polythalamia*, of the validity of which, however, he expressed himself doubtful*. In this scheme, as in our own, the essentially Arenaceous types were ranked together in a distinct group, which, like ourselves, he regarded as allied (in virtue of the absence of pores) rather to the Porcellanous than to the Vitreous series. And having subsequently come to the conclusion (which I had explicitly stated in the Chapter just referred to, § 52) that the distinction between the *Monothalamia* and the *Polythalamia* cannot be maintained, he so modified his scheme in a "Nachschrift," that it came to present a most singular conformity to that which was contemporaneously set forth in more detail in my Systematic Treatise.—This striking coincidence between the results of the studies independently pursued by Professor Reuss and ourselves, has tended, I have good reason for believing, to procure for them a general reception among Continental as well as British Zoologists, which they might otherwise have been long in gaining.

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* Sitzungsberichte der Mathem.-naturw. Classe der Kaiserl. Akad. der Wissenschaften; Bd. xliv., Wien, 1861, S. 355–396.

The *Arenaceous* group, thus definitely constituted, was considered by Messrs. Parker and T. Rupert Jones as consisting only of one Family, the Lituolida; under which they ranked the three Genera *Trochammina*, *Lituola*, and *Valvulina*, each of them possessing such a wide range of morphological variation, as to present in their aggregate a most curious series of imitations or 'isomorphs' of true shelly Foraminifera, Vitreous as well as Porcellanous. "It is not improbable," I remarked (§ 205), "that future research may add largely to our knowledge of these Arenaceous forms;" and this anticipation has been remarkably confirmed by the results of subsequent investigations. For whilst a singular variety of *recent* Arenaceous Foraminifera, some of them of large dimensions, have been brought up by the Dredging operations which have been lately carried down to great depths in the Sea, it has been discovered that certain problematical *fossils* of very regular globose form, sometimes attaining 2 inches in diameter, occurring in the Upper Greensand near Cambridge and in the Isle of Wight, and formerly supposed to be *Sponges*, are in reality gigantic *Arenaceous Foraminifera*; and the like character has been recognized in a series of fossils which were some time since brought from Persia by the late Mr. Loftus, the striking resemblance of which, both in form and general characters, to *Alveolina*, seemed to justify their assignment to the Foraminiferal type, notwithstanding that their enormous dimensions seemed almost to forbid such a determination.

Being aware that my friend Mr. H. B. Brady had made a special study of these gigantic *Alveoline* fossils, and had come to the conclusion that they constitute a new and peculiar type of Arenaceous Foraminifera, to which he has given the generic designation *Loftusia*, I thought it likely that he might be able still further to elucidate their structure by a knowledge of the results I had obtained from the examination of the non-infiltrated specimens of *Parkeria*, which I accordingly communicated to him. My anticipations were so abundantly justified by the results of Mr. Brady's re-examination of the minute structure of *Loftusia* under the new light thus reflected on it (so to speak) from *Parkeria*, that I at once perceived that it would be to our mutual advantage that the descriptions of these two extraordinary types should be associated in one Memoir; and on proposing this to Mr. Brady, I immediately obtained his cordial acquiescence. For the description of *Parkeria*, therefore, I hold myself responsible, as Mr. Brady does for that of *Loftusia*; but each of us has verified all the more important parts of the description given by the other.

It will be found that both these organisms depart so widely in general plan of structure from any Foraminiferal type previously known, that they must for the present be ranked entirely by themselves. If only *infiltrated* specimens of the Cambridge fossil had come under my examination, or if my sections even of the non-infiltrated examples had not happened to display the unquestionably Foraminiferal characters of their central "nucleus," I should have hesitated in referring them to that type on any other ground than the impossibility of finding a place for them elsewhere,—so anomalous is the structure of the concentric layers by which the "nucleus" is surrounded. It may be anticipated, however, that when the attention of Palæontologists shall have been drawn to these fossils, a much larger variety of Arenaceous Foraminifera will be brought to light, some of which may connect the anomalous *Parkeria* and *Loftusia* with types already known. And looking to the remarkable results recently obtained by Deep-Sea Dredging, especially in regard to the persistence, in the deeper parts of the Atlantic Ocean, of Cretaceous types supposed to have long since become extinct*, it scarcely seems too much to anticipate that the more extended prosecution of this inquiry may make known to us living examples of the same group, by the study of which the relationships of *Parkeria* and *Loftusia* may be completely elucidated.—For the present, therefore, I deem it better to abstain from any attempt to assign to them a Systematic rank, which can at best be only provisional.

PARKERIA.

1. More than twenty years ago, there were found by Professor MORRIS, in the Upper Greensand near Cambridge, a number of solid globular Calcareous bodies, about an inch in diameter; the superficial markings on which suggested both to himself and to Professor T. RUPERT JONES the idea that they represent a peculiar type of the *Sponges* so common in that Formation. And although the appearances presented by sections of these fossils did not correspond with the structure of any known Sponge, either recent or fossil, yet they did not suggest any other interpretation; and the question of their nature remained unsolved, until the discovery, between two and three years since, of two specimens which retain their original Arenaceous condition without any material change. The partial display of the peculiar internal structure of one of these by a superficial fracture, having led Professor MORRIS to suspect that they might constitute a new and remarkable type of *Foraminiferal* organization, he kindly placed both the specimens in my hands for examination, together with a number of previously collected specimens solidified by infiltration; giving me full permission to treat them in any way I might think most desirable for the complete elucidation of their characters. And on his surmise proving well founded, he gladly accorded with me in giving to this type a Generic designation which should connect with it the name of our valued friend and coadjutor Mr. W. K. PARKER†.

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* See my "Preliminary Report" of the *Lightning* Expedition, in the Proceedings of the Royal Society for December 17, 1868, p. 192.

† Since the above was written, I have learned that Mr. HARRY SEELEY, the Curator of the Woodwardian Museum at Cambridge, had been for several years acquainted with the fossil type I am describing, and had paid considerable attention not only to its internal structure, but also to what he believes to be its specific

2. *General Characters.*—In the two specimens which retain their original Arenaceous condition, the sphere, when laid open, is seen to be formed of a series of concentric layers (Plate LXXII.), composed of *lamellæ* of 'labyrinthic structure'*, partially separated by concentrically disposed *interspaces*, but connected at intervals by 'radial processes' which consist of large tubes that are surrounded (in all except the five or six innermost layers) by labyrinthic structure resembling that of the concentric lamellæ. As every part of the fabric is made up of sand-grains cemented together, it is very easily cut by a fine saw in any direction, so as to display in section the general structure and arrangement of the arenaceous framework. As such sections, however, are very friable, they cannot be made transparent enough to exhibit the details of their structure, except by cementing them to glass with hard Canada balsam (which should be made to penetrate them thoroughly), and grinding them down after having been thus solidified; and the specimens thus prepared are by no means equal to transparent sections of the best infiltrated specimens (§§ 3, 13). But some of the most valuable information afforded by non-infiltrated specimens is to be obtained from the examination of *fractured surfaces*; the concentric lamellæ being readily separable from one another by the introduction of a knife-blade into the interspaces. It has been by combining the information obtained through both these methods, that my able draughtsman, Mr. A. Hollick, has constructed the ideal representation given in Plate LXXII.†; which brings together in their actual relations the surfaces obtained by section and by fracture, which are separately represented on a larger scale in Plates LXXIII. and LXXIV.;—exactly as they would be seen if it were possible to remove just those portions of the fabric (and no more) whose absence is necessary to disclose them.

3. In a second set of specimens, the original Arenaceous framework has been entirely consolidated by mineral infiltration, which has completely filled all its vacuities: the infiltrating material is usually *calcareous*; but in one remarkable specimen belonging to the Museum of Practical Geology in Jermyn Street (which I have been enabled to

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variations. On communicating with him on the subject, I have received from him a ready acquiescence in the Generic designation above proposed; whilst, at the same time, he prefers to reserve the publication of the results of his own studies of this type, until after the appearance of my description of it. The series of specimens contained in the Woodwardian Museum presents a very considerable diversity of external forms; but so far as I have had the opportunity of examining their internal structure, their agreement with the globular type on which my own description is based is so complete, as to lead me to regard that diversity as a mere *varietal* modification.

* The term *labyrinthic structure* has been used in my 'Introduction to the Study of the Foraminifera' to denote an irregular aggregation of minute *chamberlets* freely communicating with each other; such as would be produced by the more or less complete subdivision of a *principal chamber* by the growth of partitions intersecting one another in various directions,—as often happens, for example, in the Arenaceous genus *Lituola* (*op. cit.* § 214). This kind of structure presents a considerable resemblance to that which, in the Anatomy of higher Animals, is termed 'cancellated.'

† Such 'built-up' figures were very successfully designed by my former draughtsman, Mr. George West, in his admirable illustrations to my previous Memoirs on this group.

examine by the kindness of Mr. Robert Etheridge), the infiltrating material is *siliceous.* In either case it is instructive to examine sections made sufficiently thin to be capable of being viewed under the Microscope by transmitted light; but whilst in the specimens in which the infiltrating material has been *calcareous*, it has usually blended with the arenaceous framework in a degree sufficient to obscure the precise boundaries of the latter, in the specimen solidified by *silex* each individual sand-grain can be distinguished, and the 'labyrinthic' structure is admirably displayed (Plate LXXVI.). The reason of this difference is probably to be found in the composition of the Sand of which these fabrics were constructed (§ 7).

4. In a third set of specimens the solidification is partial only, the infiltration having extended from without inwards through a greater or smaller number of concentric layers; and in these the original Arenaceous framework of the unconsolidated interior has for the most part disappeared, so that the spheres, when laid open, are found to be hollow, the central cavity being occupied only by loose sand-grains, or being altogether void. In such specimens the consolidated portion is usually very dark and opaque, so that sections can with difficulty be rendered thin enough for being viewed by transmitted light.—It is worth notice that in one of these specimens of which the outer layers have been completely consolidated, these are succeeded by partly unconsolidated lamellæ, and these again by another set of lamellæ whose consolidation is complete; and this alternation repeats itself twice as we pass inwards to the central vacuity, which in this instance has a diameter only about one-fourth that of the entire sphere.

5. The *diameter* of the largest *Parkeria* which I have seen (this being a specimen from the Isle of Wight, in the British Museum) is exactly 2 inches; that of the smallest (the silicified specimen in the Museum of Practical Geology) is ·75 inch. Other specimens range between these two extremes; the average diameter of those I have seen being somewhat less than an inch.

6. The *External Surface* of the silicified specimen is covered with small rounded elevations separated by intervening depressions, so as closely to resemble that of a mulberry (Plate LXXII.); and I am disposed to believe that this is the normal condition of the fabric,—the dissimilar kinds of surface presented by other individuals being probably the result of abrasion. Thus in one of the specimens in my possession, which has not been solidified by infiltration, the summits of the tubercles have been worn off by abrasion, so as to lay open their labyrinthic structure, the surface of the depressed portions remaining unbroken; whilst in another, which has undergone infiltration, the surface is everywhere uniform, as if the tubercles had been rubbed down to the level of the intervening depressions. In some other cases, however, a condition of surface precisely the reverse of the first is observable, the rounded elevations being replaced by depressions which are separated by elevated ridges: and this seems to depend upon the consolidation of the originally depressed portions by infiltration, whilst the tubercles and the areolæ from which they rose continued uninfiltrated; so that abrasion would have the effect of wearing down the latter (as the more friable substance) even below

the level of the former, and would thus cause the solidified portions to project as ridges. —That the infiltrating material might more readily penetrate the substance of the depressed portions than that of the tubercles, will become evident when it has been shown that whilst the latter is the most solid portion of the fabric, being minutely labyrinthic throughout, the former is composed of a mere layer of labyrinthic structure, having large cavities beneath it (see § 17).

7. Although I have spoken of the *Material* of which these fabrics are mainly composed as 'sand,' yet its composition is very peculiar. When a portion of a non-infiltrated specimen is treated with very dilute Nitric acid, a slight effervescence takes place, and the arenaceous particles fall asunder. But when these are treated with stronger nitric acid, by far the larger proportion of them is dissolved; only a small residue remaining insoluble in the strongest acid. Hence it appears (1) that the Arenaceous particles are held together (as in many other Arenaceous Foraminifera) by a cement of Carbonate of Lime, which, however, forms no large proportion of the whole; and (2) that, although Siliceous sand-grains do occur in small proportion, the principal part of the Arenaceous material is *not* siliceous, but (being soluble in moderately strong nitric acid) is probably Phosphate of Lime. This proves, in fact, to be the case; a careful analysis, made under the direction of Mr. H. B. Brady, having given the following results:—

Phosphate of Lime	59·7
Carbonate of Lime	26·0
Silica	9·0
Iron and Alumina	0·9
Magnesia, Manganese, Organic Matter, &c. . . .	4·4
	100·0

8. In several of the specimens which have been partially or completely infiltrated, the chamberlets and sometimes even the large interspaces of the external layers are occupied by a substance which presents a green colour alike by transmitted and by reflected light: this probably consists of the Silicate of Iron, Alumina, and Magnesia, of which the ordinary green particles of the Upper Greensand Formation are composed,—these particles, as Professor Ehrenberg* has shown, being really the chamber-casts of *Foraminifera* whose calcareous shells have entirely disappeared.

9. *Internal Structure.*—Proceeding now to the details of the internal structure of these singularly fabricated bodies, we shall find it convenient, as in the case of the discoidal *Orbitolites* (Philosophical Transactions, 1856, p. 194), to distinguish between the *Nucleus* and the *Concentric Layers* that surround it.

10. The *Nucleus*, as shown *in situ* in Plate LXXII., and on a larger scale in Plate LXXIII. (divided transversely in fig. 1, and longitudinally in fig. 2), is composed of a series of chambers, c^1–c^5, which are laid end to end in a rectilineal direction; the series,

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* "Ueber der Grünsand und seine Einläuterung des organischen Lebens," in Abhandlungen der Königlichen Akademie der Wissenchaften, Berlin, 1855.

of which the transverse section is somewhat elliptical, having apparently commenced at the small extremity, and having very gradually widened until it ended abruptly at d*. The chambers are separated by septa, each composed of a single layer, which are extremely sinuous, like those of many *Ammonites.* Of the mode of communication between the chambers, I am unfortunately not able to speak; for although, by a happy accident, the sections of the only two uninfiltrated specimens yet examined, passed through the nucleus in such a manner as to lay it open transversely in one and longitudinally in the other, the portions of the septa traversed by the aperture are not exhibited in either—both the chamber-walls and the intervening partitions appear so perfectly homogeneous in texture, even under a magnifying-power of 80 diameters, that I was at one time inclined to regard them as composed of proper shell-substance, corresponding with that of the Porcellanous *Foraminifera*, and free from any admixture of arenaceous particles,—its soft and friable texture bearing a close resemblance to that of the fossil *Orbitolites* of the Paris Basin. As the like appearance, however, is presented by the walls of the 'radial tubes,' which I have found to have the same Arenaceous composition as the remainder of the fabric (§ 14), I am now disposed to believe that the chamber-walls of the Nucleus are not exceptional in any other respect, than in the fineness of the particles by the aggregation of which they have been built up.

11. The general aspect of the *Concentric Layers* enclosing the Nucleus, as presented by a section whose plane passes through the centre of the sphere (Plate LXXII.), bears some resemblance to the median plane of an *Orbitolite* laid open by the removal of one of its superficial layers. (See Philosophical Transactions for 1856, Plate V., fig. 6.) But this resemblance diminishes on a closer comparison; and disappears entirely when the details of the structure are examined with adequate magnifying-power. For whilst in *Orbitolites* the vacuities are *chambers*, symmetrically arranged in annular series, and communicating with each other by a regular system of circular galleries and radiating passages, which traverse the intervening solid shell-substance that forms the walls of those chambers,—the vacuities in *Parkeria* are merely irregular *interspaces* left between successive *lamellæ*, each of which is composed of a 'labyrinthic' or *cancellated* substance, made up of minute *chamberlets* separated by irregularly-disposed partitions, but freely communicating with each other; and these vacuities are traversed by radiating tubes, which establish a direct communication between the 'labyrinthic system' of each layer, and that of the layers internal and external to it. Each of the concentrically spherical lamellæ of *labyrinthic substance*, together with the *interspace* (traversed by

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* There is probably considerable variety in the disposition of the chambers of the Nucleus. In some specimens from the Isle of Wight (contained in the British Museum), which, by the kindness of Mr. WOODWARD, I have had the opportunity of minutely examining since the above was written, the chambers are more numerous, and the axis of growth is not rectilineal but *spiral*; and in the largest of these specimens the spire actually turns back on itself. The precise correspondence in structure between the Concentric Layers of these specimens, and those of the specimens described in the text, leaves me in no doubt that the direction of the axis of growth of the Nucleus has no essential significance.

the 'radial tubes') which separates it from the lamella that encloses it, may be conveniently considered as *one layer*; and it will be found to be entirely on the differences in the proportions of these two components, that the diversities of aspect presented by the several parts of the sectional plane depend. Thus it will be observed in Plate LXXII., and on a larger scale in Plate LXXIII. fig. 1, that in the twelve concentric layers which surround the 'nucleus,' the breadth of the interspaces is twice or thrice the thickness of the solid lamellæ; but that in certain parts of the outer four of these layers, the solid lamellæ send irregular 'processes' across the interspaces, so that the 'labyrinthic systems' of successive lamellæ are brought into connexion not merely by the 'radial tubes,' but by direct continuity of cancellated structure. These layers are surrounded by a layer (l^1, l^1) of labyrinthic structure unbroken by any interspace, which is equal in thickness to any two of the layers it encloses. We then come to a second series of twelve layers, of greater thickness than the first; the increase being due to the greater development of the 'labyrinthic system' of each lamella, whilst the breadth of the interspaces remains the same; so that the breadth of the interspaces and that of the solid lamellæ are now nearly equal. But we here notice that the interspaces, instead of being traversed by the irregularly disposed 'radial tubes' of the inner layers, are crossed at pretty regular intervals by 'radial processes' of labyrinthic substance, which (as will be shown hereafter) form an investment to the radial tubes; and thus the concentric interspaces that separate the successive solid lamellæ from the lamellæ internal and external to them, are divided into a number of small cavities having little communication with each other. This series of layers is separated by a second thick lamella (l^2, l^2) of labyrinthic substance, the breadth of which somewhat exceeds that of the first. And around this is a third series of seven concentric layers, which closely resemble those of the second, except that the radiating bands of labyrinthic substance are broader, so that the interspaces which they cross and divide form in the aggregate but a yet smaller proportion of each layer. The thick lamella (l^3, l^3) of labyrinthic substance which encloses these, the five ordinary layers by which it is invested, and the yet thicker lamella (l^4, l^4) of labyrinthic substance which forms the exterior of the sphere, correspond in all essential particulars with those already described.

12. Thus we see that in passing from the centre to the circumference of the sphere, we meet with a progressive increase in the proportion which the comparatively solid 'labyrinthic system' bears to the 'interspace-system' of the successive layers; so that the solidity of the fabric as a whole augments with its increase in size. And this seems to be a general character of the type; although there is found to be no constancy, when different individuals are compared, in regard to the number of *ordinary* layers that intervene between the peculiarly thick lamellæ by which the general regularity of the former is interrupted.

13. We shall now examine, in more detail, such a portion of a group of *Concentric Layers* about halfway between the centre and the periphery of the sphere, as may be taken to present the plan of structure characteristic of the fabric generally; after the

study of which it will be found more easy to understand the variations from this plan that present themselves (1) in the *first*-formed layers which immediately surround the nucleus, and (2) in that *last*-formed layer which constitutes the exterior of the fully-developed sphere.—Such portions are shown in transverse section, as seen by reflected light under a power of 25 diameters, in Plate LXXIII. figs. 3, 4; whilst another portion that combines certain features presented separately in the two preceding, is shown in transparent section, by transmitted light, under a power of 70 diameters in Plate LXXVI. fig. 1. In the latter of these figures, to which the attention may be most advantageously directed in the first instance, is seen a succession of four lamellæ (l^1l^1, l^2l^2, l^3l^3, l^4l^4) of labyrinthic substance, separated in the middle portion of the figure by interspaces which are for the most part wider than the lamellæ themselves, but continuous with each other on either side. Each lamella is bordered on its *inner* or *centrad* aspect by a *continuous floor* (fl^1, fl^2, fl^3, fl^4) composed of adherent sand-grains; which completely closes-in the labyrinthic structure along that face, and cuts off its chamberlets from the contiguous *internal* interspace,—as is yet more distinctly seen in another transparent section which crosses the interspaces in the contrary direction (Plate LXXV. fig. 1), and in the opaque sections (Plate LXXIII. figs. 3, 4). On this floor are built up (so to speak) the partitions which intervene between the chamberlets; but these are so far from being complete, that the cavities they surround remain in free communication with each other. There is generally to be observed, just above the floor, a row of openings more regularly arranged than those seen elsewhere (as is best shown in Plate LXXIII. fig. 3); and the disposition of these seems to indicate that they are the cross sections of *passages* running at right angles to the plane of section, like the longitudinal galleries which form the communications between the contiguous series of chamberlets in *Alveolina*. (See Philosophical Transactions, 1856, Plate XXIX. fig. 8, *bb*, *cc*.) The partitions between the chamberlets, which are composed (like the floor) of sand-grains cemented together, have a generally vertical (or radial) direction; but they show no such regularity as would enable it to be said that they are arranged on any definite plan. They are not covered in by any layer corresponding to their floor; so that the chamberlets open freely into the interspace above; and as this lies on their *peripheral* aspect, they must have been similarly open to the surrounding medium, when the layer of which they form part constituted the external surface of the sphere.—The contrast between the *open* or *external* surface of each layer of labyrinthic structure, and its *closed* or *internal* surface, is best displayed by *concentric fractures* separating two contiguous layers; as shown in Plate LXXIV. figs. 1 and 2, 3 and 4, of which a detailed description will be found in the next paragraph.

14. It has been already pointed out, in the account of the general structure of *Parkeria* (§ 11 and Plate LXXII.), that the interspaces between the successive lamellæ are traversed by *radial processes* composed of labyrinthic structure resembling that of the lamellæ themselves; which bring the 'labyrinthic systems' of several successive lamellæ into continuity with each other, as is shown at *rp*, *rp*, $r'p'$, $r'p'$, in the highly magnified section represented in Plate LXXVI. fig. 1. It is only by concentric fractures, however,

whereby the opposed surfaces of the lamellæ are separated from each other, that the form and arrangement of these 'radial processes' can be properly studied; and the appearances presented by the surfaces thus exposed are found to vary, according as the plane of fracture has passed through the middle of the interspace, or nearer to one of the lamellæ. The former has been the case with the pair of lamellæ of which portions of the opposed surfaces are shown in Plate LXXIV. figs. 1, 2; the latter with the pair of which the outer lamella, carrying with it the 'radial processes,' is shown in fig. 3.—In fig. 2, which represents the *external* surface of part of a lamella thus detached, we see the labyrinthic structure *l*, *l*, opening freely into the interspaces; whilst these cavities are separated by a set of projections (*rp*, *rp*) more or less rounded in form, but connected with each other by bridging extensions. These are the 'radial processes,' which have been broken across and laid open by the fracture. The converse aspect is shown in fig. 1, which represents the *internal* surface of the lamella that immediately surrounded the preceding; for its deeper parts, which constitute the peripheral boundary of the interspace, are here covered by an uniform floor, *fl*, *fl*, that cuts them off from the labyrinthic substance beneath; whilst the radial processes *rp*, *rp*, which rise as elevations from this floor, are here less connected together, so that the interspaces form a more continuous system. The interior of the 'radial processes' thus laid open by transverse fracture is found to consist of labyrinthic structure rather coarser and less regular than that of the lamellæ they connect; but in each of them there is at least one large aperture, whilst not unfrequently there are two or even three; and these are the cross sections of 'radial tubes' exactly corresponding with those which are seen in the inner layers (Plate LXXIII. figs. 1, 2) without any investment of labyrinthic substance.—These 'radial processes' have not unfrequently a somewhat conical form, the apex of the cone being applied to the *outer* surface of the enclosed lamellæ (with which its connexion is consequently slight); whilst its spreading base becomes continuous with the inner surface of the investing lamellæ, into the labyrinthic system of which its own cancellated structure opens. Hence, when the plane of fracture passes through the apical portions of the cones (where the resistance to the disruption of the layers is the least), the 'radial processes' remain in connexion with the investing lamella, as shown at *rp*, *rp*, Plate LXXIV. fig. 3; where are also seen the continuous floor, *fl*, *fl*, that cuts off its labyrinthic system from the interspace on its internal aspect, and the orifices, *t*, *t*, of the radial tubes laid open by the fracture.

15. When, however, as sometimes happens, the concentric fracture passes through the thickness of a lamella, instead of through the interspaces and the radial processes which cross them, its labyrinthic system is laid open in the manner shown at Plate LXXIV. fig. 4; where we also see its chamberlets opening into the cavities of the 'radial tubes' *t*, *t*, *t*, which pass into its substance.—This connexion, however, is best brought into view when these tubes are laid open longitudinally, either by fracture or by section; as in the fractured surface shown in Plate LXXIII. fig. 4; where we see that the cavity of the tube *t* is formed (so to speak) by the coalescence of passages from the labyrinthic

system which surrounds its base; and still better in the transparent section represented in Plate LXXVI. fig. 1, where two of the interspaces are seen to be traversed by 'radial tubes' t^1, t^2, which do not form part of the ordinary 'radial processes.' A careful examination of the entire section of which only a small part is here figured, has fully satisfied me of the universality of this communication; notwithstanding that (as at the upper part of the tube t, Plate LXXIII. fig. 4) it often appears to be interrupted,—the fracture or section not having happened to lay open the apertures or passages of connexion. And further, I have been enabled to satisfy myself, by the use of adequate magnifying power, that notwithstanding the smooth *shelly* aspect which the walls of the 'radial tubes' often present, they are in reality built up, like the lamellæ between which they pass, of aggregated sand-grains,—a fact which may be regarded as justifying the like interpretation of the appearance presented by the substance of the Nucleus (§ 10).

16. When a sufficiently high magnifying-power is applied to transparent sections thin enough to bear it, so as to bring into view the forms of the individual sand-grains and the mode of their aggregation, a curious diversity is observable as to both these particulars between different individuals. In the two non-infiltrated specimens I have thus examined, the sand-grains are angular, and are fitted together with marvellous exactness, as shown in Plate LXXV. fig. 2; in which we see, moreover, that each of the partitions, p, p, which separate the chamberlets c, c, is formed of at least three layers of apposed sand-grains. In the specimens which have undergone *calcareous* infiltration, the forms of the individual sand-grains cannot be clearly made out; but in the thickness and solidity of the partitions between their chamberlets, they agree with the preceding. In the specimen which has undergone *siliceous* infiltration, however,—of which the general structure as displayed in section has been already demonstrated (Plate LXXVI. fig. 1),—the application of a higher magnifying-power shows that the individual sand-grains have a somewhat rounded form (fig. 2), and are more loosely fitted together; and further, that the partitions between the chamberlets are formed of only a single layer of sand-grains. Hence the cement furnished by the animal must have probably borne a larger proportion to the sand-grains obtained from without, than it did in the spheres of which the component sand-grains are so closely fitted together that there seems no room for any uniting medium; and the arenaceous structure of this individual must have been far less solid and compact than that of any of the other specimens yet examined. The difference in the form of the sand-grains must have been pretty certainly due to difference of locality, this specimen not having been obtained with the others, but forming part of a distinct collection. Whether the difference in general solidity had any relation to the nature of the material employed, can of course be only determined by the examination of other specimens whose component sand-grains exhibit the same character; but it seems a *possible* supposition that as the *rounded* form of the sand-grains must have required more cement to unite them, a limitation in the quantity of this cement capable of being furnished by the animal might have prevented it from aggregating the number of sand-grains which are found in such close apposition

in the more solid fabrics.—It is difficult to conceive the means whereby the pseudopodial filaments projected by the sarcode-body, which must have been the instruments employed to collect the sand-grains, were enabled to fit them together with a precision that could not be exceeded by the most dexterous mason, employed to build up angular stones of every variety of shape, with the smallest possible quantity of intervening cement, into a wall of uniform thickness and general regularity of surface. But a precisely parallel case occurs among existing Arenaceous *Foraminifera*, as I have elsewhere shown*.

17. Notwithstanding the apparently well-marked difference between the structure of the layers now described, and that of the earliest layers represented in Plate LXXIII. figs. 1 & 2, we shall find this difference to consist almost entirely in the *proportions* of the component structure. The labyrinthic substance in the latter case presents itself in an almost rudimentary condition, the *lamellæ* being very thin, whilst the *interspaces* between them are very wide, the entire thickness of the *layers*, which are composed of lamellæ and interspaces taken together, being about the same as elsewhere. The width of the interspaces, and the absence of the labyrinthic structure which elsewhere forms the 'radial processes,' makes the 'radial tubes' very conspicuous; and they are somewhat more closely set than in the outer layers. The first trace of labyrinthic substance is seen in the wall of the Nucleus itself, alike in transverse and in longitudinal section (*l*, *l*, figs. 1, 2, Plate LXXIII.); from this, as from a base, spring a number of hollow pillars, the 'radial tubes,' whereon the first of the investing lamellæ is supported, of which the cancellated structure is scarcely more developed; and this again serves as a base for another set of radial tubes, that support a second lamella in which the cancellated structure is somewhat more obvious.—In the *transverse* section (fig. 1), we see that the earlier layers do not pass completely round the nucleus, their disposition being somewhat excentric, as is very commonly the case with the earlier zones of *Orbitolites* (see Philosophical Transactions, 1856, pp. 217, 218); it will be seen, however, on reference to Plate LXXII., that the regularly concentric arrangement is soon established in this direction. In the *longitudinal* section (fig. 2), however, the earlier lamellæ are seen to be considerably less complete, enclosing but a small part of the length of the nucleus; which does not seem to be encased at both its extremities, until four or five of such incomplete lamellæ, each extending somewhat further than that which preceded it, have been formed upon the surface of the elongated primordial chambered cone. Proceeding further outwards, we find the concentric lamellæ progressively increasing in thickness, in consequence of the augmented development of their labyrinthic structure, while the interspaces are proportionately narrowed; and we see the labyrinthic system of one lamella occasionally putting forth irregular outgrowths, which cross the interspaces (usually clustering round the 'radial tubes'), and become continuous with the labyrinthic system of the succeeding lamella. Towards the outer part of this series of layers, which ends with the first *thick* lamella (l^1, Plate LXXII.), not only does the thickness of

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* 'Introduction to the Study of the *Foraminifera*,' § 213, and Plate VI. fig. 41.

the labyrinthic substance of the lamella come to equal that of the interspaces, but its peripheral extensions exhibit increased regularity, and become the 'radial processes' already described as characteristic components of the subsequently-formed layers.

18. Passing now to the *outer* or *last-formed* portion of the sphere, we find it to consist of a solid layer of cancellated substance, resembling the solid layers (l^1, l^2, l^3, Plate LXXII.) by which we have seen the regular growth to have been previously interrupted, but of greater thickness and coarser texture (Plate LXXIV. fig. 5). Its inner surface is bounded, like that of the ordinary lamellæ, by a continuous floor (*fl*, *fl*, *fl*) which cuts off its chamberlets from the neighbouring interspaces (*int*, *int*); but its labyrinthic system is connected with that of the lamella it encloses by the radial tubes (*t*, *t*); and these seem to extend through nearly the whole thickness of the layer, each being the centre, as shown in Plate LXXV. fig. 4, of a group of chamberlets disposed around it (like the cells clustered round the vascular canals in an ossifying cartilage), with all of which it is probably in direct or mediate communication. If each of these tubes (as appears probable) served as a centre of growth, conveying a stolon-process of sarcode from the subjacent lamella, it may be readily conceived that the group of chamberlets which surrounds it would project from the general surface, at any rate during the period of most rapid increase; and that thus would be produced the tuberculated aspect, by which, as already stated (§ 6), the specimens that seem best to represent the original condition of the organism are characterized. It may be considered not improbable, however, that the intervening depressions were subsequently filled up by the growth of the cancellated substance, so as to constitute one uniform surface.

19. The strongly marked dissimilarity between the fabric of *Parkeria* as now described, and that of any FORAMINIFERA previously known, whether recent or fossil, renders it impossible to predicate with certainty what was the precise relation of the sarcode-body of the animal to its Arenaceous 'test.' Looking to the manner in which the earliest cancellated lamellæ are attached to the surface of the original chambered cone, it cannot, I think, be doubted that the sarcode which occupied the latter spread over its exterior, as in *Foraminifera* generally*; and that it was by this layer of sarcode that the walls of the first labyrinthic structure were built up. The mode in which each subsequent cancellated lamella was formed, however, not in immediate superposition on that which preceded it, but separated from it by a considerable interspace, and only connected with it by the 'radial tubes,' is not so easily conceived. That each of these tubes contained a 'stolon-process' from the sarcodic substance of the previous lamella, may be considered next to certain. And the manner in which the chamberlets of the succeeding lamella are grouped around the extremities of the 'radial tubes,' seems to indicate that the extensions of these sarcodic 'stolon-processes' furnished the instrumentality by which the materials were collected and arranged for rearing the walls of those chamberlets. It is difficult, however, to conceive (1) how the solid *floor* was laid, upon which those walls were built up (§ 13), if this floor was entirely destitute of support from beneath; and (2)

* 'Introduction to the Study of the *Foraminifera*,' §§ 33–36.

how, if the laying of this floor was effected by the junction of peripheral extensions formed around the extremities of independent 'radial tubes,' its surface should possess the regular continuity by which we find it characterized. In the somewhat analogous case of *Tubipora musica*, it is well known that the transverse lamellæ connecting the polype tubes at intervals, which are formed by lateral extensions from the several tubes whose vertical growth sustains an occasional interruption at those points, are far from exhibiting such regular continuity. And with the knowledge we have of the general indefiniteness and polymorphism that prevails among the various groups included under the RHIZOPOD type, it seems still less to be expected that the multitude of 'radial tubes' proceeding from one lamella of *Parkeria* should all *simultaneously* cease to extend themselves longitudinally, and should give off lateral processes with such perfect uniformity that their coalescence should form a continuous lamella exactly concentric with the preceding, though connected with it only by the hollow pillars which traverse the interspace. On the other hand it is to be remarked that, as all the chamberlets of each lamella open freely on its exterior, the surface of that lamella, whilst as yet uninvested by a subsequent growth, may be presumed to have been covered by a continuous layer of sarcodic substance, in freest connexion with that which occupied its own labyrinthic substance. And it would seem not improbable, therefore, that the continuous imperforate floor of the superposed lamella should have been laid by the instrumentality of this layer upon its own surface; which must then have been completely cut off by it from direct connexion with the surrounding medium. Such communication must thenceforth have been only maintained indirectly, through the 'stolon-processes' occupying the 'radial tubes;' the extensions of which, spreading themselves out on the external surface of the floor of the new lamella, would build up the walls of the chamberlets, and would occupy their cavities,—becoming in their turn the base of a new sarcodic investment of what would then be the external layer of the sphere, which, in due course, would itself be enclosed by another lamella, of which the imperforate floor would be modelled on its own surface.

20. The question naturally arises whether each sarcodic layer, when it had completely floored over the interspace it may be supposed to have filled, continued to occupy that interspace; or withdrew itself into the labyrinthic system of its own lamella, and then projected itself through the radial tubes into the labyrinthic system of the next. To this question no positive answer can be given, since no recent organism is known, in which any analogous arrangement exists. But the former of the two alternatives seems to me the more probable, on the following grounds. If the sarcodic segments were withdrawn from the interspaces, their place must have been taken by some other material; since that a *vacuum* should have been left, is of course inconceivable. How *air* could have found its way into them, is scarcely more conceivable; since these organisms must have been living, like recent Arenaceous Foraminifera, on the bottom of the sea, probably at a considerable depth. If any direct communications had existed between the interspaces belonging to different layers, and between those of the penulti-

mate layer and the exterior, it might be thought not improbable that these interspaces were filled with water from without, and constituted a kind of aquiferous system. But since it may be certainly affirmed that no such passages existed, and that the interspaces had no other communication with the exterior than through the systems of radial tubes connecting the labyrinthic systems of successive lamellæ, which must certainly have been occupied by the sarcode-body of the animal, there was no provision for the admission of water to the interspaces, or, if it did enter to replace the sarcode on its withdrawal from them, it must have remained stagnant in these recesses. If, on the other hand, the interspaces remained full of sarcode through the whole life of the organism, there is no difficulty in comprehending that, though cut off from direct communication with the exterior, the sarcodic segments of the interspaces would share in the vital activity of the entire composite mass. Knowing what we do of the semifluid condition of living protoplasm, and of the interchange which is incessantly taking place between the component particles of the segments, however numerous and segregated they may be, into which the sarcodic body of one of these aggregate organisms is divided, there is not the least difficulty in understanding how nutritive material might have been conveyed through the radial system into the innermost *penetralia* of the sphere of *Parkeria*, notwithstanding their investment by any number of concentric layers, however thick*.

Explanation of the Plates of Parkeria.

PLATE LXXII.

Ideal representation of the internal structure of *Parkeria*; the different parts shown in Plates LXXIII. and LXXIV. (from actual specimens) being here combined so as to show the relations of those parts to each other. In the upper transverse section, of which the plane passes through the centre of the sphere, the general arrangement of the concentric layers around the primordial chamber-cone is displayed; and the interruption of the ordinary alternation of solid lamellæ and interspaces crossed by radial processes, by the interposition of the four thick layers l^1l^1, l^2l^2, l^3l^3, and l^4l^4, is shown. The details of the structure of the layers immediately surrounding the chambered cone are represented on a larger scale in Plate LXXIII. figs. 1, 2; and the details of the structure of the thick layers are shown in Plate LXXIV. fig. 5.—In the vertical planes, A shows the *internal* surface of a lamella separated by concentric fracture, the conical radial processes remaining attached to it, as represented on a larger scale in Plate LXXIV. fig. 3:—B shows the appearances presented by a similar fracture which has passed through the radial processes, so as to lay open their cancellated structure, as represented on a larger scale in Plate LXXIV. fig. 1:—C shows the result of a tangential section passing through the cancellated substance of a lamella, as represented on a larger scale in Plate LXXIV. fig. 4:—D shows the appearances presented by the *external* surface of a lamella separated by a concentric fracture which has passed through the radial processes, as represented on a larger scale in Plate LXXIV. fig. 2;—and E shows the aspect of sections taken in a radial direction, so as to cross the solid lamellæ and their intervening spaces, as represented on a larger scale in Plate LXXIII. figs. 3, 4.—Magnified 7 diameters.

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* In my Memoir on *Orbitolites* (Philosophical Transactions, 1856, §§ 12, 34) I showed that the entire disk, however numerous may be the concentric zones of which it is formed, is occupied during life by the sarcodic body of the animal, which continues to fill even the primordial chamber; notwithstanding that this chamber and the zones that surround it are in but very indirect relation with the exterior, through the pores of the peripheral zone. And since the above was written, I have obtained from the Deep-Sea Dredgings of the *Porcupine* Expedition (1869) a complete confirmation of the view taken in the text. For on examining the internal structure of the largest nautiloid *Lituolæ*, I find extensions from each chamber-cavity prolonged into its thick arenaceous wall; which thus presents, though in a rudimentary condition, a labyrinthic structure whose relation to the chamber it surrounds is essentially the same as in *Parkeria*.

PLATE LXXIII.

Fig. 1. Portion of section which has cut the central chambered cone transversely:—*s*, one of its sinuous partitions; *l*, *l*, the first layer of labyrinthic structure, built up on its external wall, around which are seen successive layers of the like structure, separated by interspaces which are traversed by the radial tubes, *t*, *t*, *t*, *t*, one of which is seen laid open at *t'*. Towards the right-hand side of the figure, the progressive increase in the amount of labyrinthic structure in each concentric layer is apparent.—Magnified 25 diameters.

Fig. 2. Portion of section which has cut the chambered cone longitudinally:—c^1, c^2, c^3, c^4, c^5, its successive chambers separated by sinuous partitions; *d*, its termination, with the commencement of the labyrinthic structure shown at *l*.—Magnified 25 diameters.

Figs. 3, 4. Portions of sections traversing the concentric layers in a radial direction, so as to show the manner in which the cancellated structure of each lamella is built up on a solid layer or floor, *fl*, which cuts it off from the interspace, *int*, beneath it. In fig. 3 the manner in which the interspaces are bounded laterally by the radial processes connecting the successive layers is well seen; and in fig. 4 two of the radial tubes, *t*, *t*, contained in those processes are shown laid open, so as to exhibit their connexion with the labyrinthic structure.—Magnified 25 diameters. The free communication of the labyrinthic structure on its outer or peripherad aspect, with the interspace separating each lamella from that which succeeds it, is well seen in both figures; the *lower* margin of which looks towards the *centre* of the sphere, and the *upper* to its *periphery*.

PLATE LXXIV.

Fig. 1. Portion of the *internal* surface of a lamella, separated from that whereon it was deposited, by a concentric fracture which has passed through the radial processes *rp*, *rp*, in each of which are seen one or more large orifices of the radial

tubes. At *fl*, *fl* is shown the solid floor, cutting off the labyrinthic structure of the lamella from the interspace which separates it from the previously formed lamella whereon it rests.—Magnified 25 diameters.

Fig. 2. Portion of the *external* surface of the layer from which the layer represented in the preceding figure had been removed by concentric fracture:—*rp*, *rp*, radial processes; *l*, *l*, labyrinthic structure opening freely into the interspaces.—Magnified 25 diameters.

Fig. 3. Portion of the *internal* surface of a lamella separated from that whereon it was deposited, by a concentric fracture passing through the apices of the conical radial processes, *rp*, *rp*, so as to leave them adherent to it:—*fl*, *fl*, the solid floor, continued over the surface of the radial processes, so as to cut off their labyrinthic structure from the interspaces they bound;—*t*, *t*, orifices of the radial tubes laid open by the fracture.—Magnified 25 diameters.

Fig. 4. Tangential section of a lamella, showing its labyrinthic structure, with the orifices *t*, *t* of the radial tubes cut transversely or obliquely.—Magnified 25 diameters.

Fig. 5. Radial section of the thick outer layer (Plate LXXII. l^4), showing its coarsely labyrinthic structure, in the midst of which are seen the orifices of radial tubes, *t*, *t*, and which is separated by the solid floor *fl*, *fl*, from the interspaces *int*, *int* beneath.—Magnified 25 diameters.

PLATE LXXV.

Fig. 1. Transparent section of part of a lamella taken in a radial direction; showing its labyrinthic structure cut off on its internal or centrad aspect from the interspace int^1 which separates it from the previously formed lamella, by the interposition of the solid floor *fl*, *fl*; while on its external or peripherad aspect it freely communicates with the next interspace int^2, which is bounded peripherally by the internal floor, fl', fl', of the next lamella.—Magnified 30 diameters.

Fig. 2. Portion of the same section enlarged to 250 diameters, to show the arrangement of the sand-grains of which the framework is built up:—*p*, *p*, *p*, section of partitions, enclosing the chamberlets *c*, *c*; *fl*, *fl*, part of the floor of the labyrinthic structure.

Figs. 3 and 4. Portions of thin tangential sections of lamellæ of an infiltrated specimen, viewed as transparent objects; showing their cancelli grouped around the radial tubes, whose orifices are seen at *t*, *t*. The interspaces are occupied by crystals of calcite.—Magnified 30 diameters.

Fig. 5. Portion of a thin transparent section of an infiltrated specimen, showing the appearances it presents under a magnifying-power of 15 diameters. On the *left* side the section traverses the layers *tangentially*; and the labyrinthic structure of the lamellæ, the transverse sections of the radial tubes, and the

interspaces filled with crystals of calcite, are obvious. Towards the right side the section comes to traverse the layers *radially*; and we see the connexion of the labyrinthic structure of the successive lamellæ by the radial processes, between which lie the interspaces filled with calcite. The solid floors separating the superposed lamellæ from these interspaces are well seen at *fl*, *fl*.

PLATE LXXVI.

Fig. 1. Portion of a radial section of a specimen infiltrated with silex, showing the details of the structure of the concentric layers:—l^1l^1, l^2l^2, l^3l^3, l^4l^4, four successive lamellæ, showing their labyrinthic structure, built up on the impervious floors fl^1, fl^2, fl^3, fl^4, and opening above into the successive interspaces int^1, int^2, int^3; at *rp*, $r'p'$ are seen the radial processes by which these interspaces are bounded; and at t^1, t^2 are seen two of the radial tubes laid open longitudinally.—Magnified 70 diameters.

Fig. 2. Portion of the preceding enlarged to 250 diameters, to show the arrangement of the component sand-grains.

LOFTUSIA.

21. The extraordinary nature of the remains of FORAMINIFERA discovered within the past few years in the Palæozoic rocks of Canada, has in many ways affected previously received views concerning the testaceous RHIZOPODA. In no respect is this so manifest as in the increased importance accorded to the whole group, on account of the *size* of its newly added members. On the first separation of the Foraminifera from the Mollusca, *minuteness* was regarded as a distinctive character of the suborder; and though it was found necessary to place the *Nummulites* in a systematic series, which consisted otherwise of microscopical organisms, they were looked upon as exceptional, in point both of magnitude and of complexity of structure. The discovery in recent times of specimens belonging to larger types, such as those dredged off the coast of Borneo by Sir EDWARD BELCHER, and subsequently described by Dr. CARPENTER under the generic name *Cycloclypeus**, scarcely excited sufficient attention to affect the general idea that the group was composed of animals of insignificant dimensions; and it was not until the announcement and description by Dr. DAWSON, of Montreal, in 1864, of *Eozöon Canadense*, that the views of Naturalists became modified as to the size attainable by a class of animals of so simple an organization. It is perhaps not too much to say that the controversy respecting the Protozoic, or at least the Animal, origin and characters of the remains of *Eozöon*, though eventually centering in questions of minute structure, would never have arisen at all, but for doubts initiated by the dimensions of the fossil. To those who have made the lower forms of animals their special study, the peculiar arrangement of the calcareous shelly layers on an acervuline plan of growth, already well observed in other types of Foraminifera, whilst it accounts for the irregular and asymmetrical external

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* Philosophical Transactions, 1856, p. 547.

contour of the Canadian fossil, equally explains the indefinite extension of the shell-masses.

22. The addition of *Receptaculites* to the list of probable FORAMINIFERA, and the suggestion that *Stromatopora*, *Archæocyathus*, and some other obscure fossils, hitherto regarded as SPONGES in the absence of any very accurate knowledge of their structure, may find their nearest allies in the same category, are indications of a field of research from which great results may be anticipated. At the present moment, therefore, any investigations tending to throw light on what may properly be termed the *gigantic* types of Foraminifera have greatly enhanced interest.

23. Amongst the fossils collected by the late WILLIAM KENNETT LOFTUS, during his Archæological and Geological researches near the line of the Turko-Persian Frontier*, were certain somewhat obscure bodies, oval or fusiform in shape, and occurring in sufficient abundance to give a special character to the rock in which they were imbedded. As they bore a general resemblance to some forms of *Alveolina*, a well-known genus of Foraminifera, from which, indeed, they seemed to differ in point of *size* rather than in any structural peculiarities revealed by a cursory examination, they were assigned by their discoverer to that genus; and, having attracted but little subsequent attention, have been left by Palæontologists in the same position.

24. In Mr. LOFTUS's memoir† these fossils are spoken of as specimens "of a gigantic species of *Alveolina* 3 inches in length;" but no further mention is made of them. Messrs. W. K. PARKER and T. RUPERT JONES, in one of their earlier papers on the "Nomenclature of the Foraminifera"‡, make a passing allusion to them. Amongst their notes on the fossil forms of *Alveolina*, especially those of the Nummulitic Period, they say, "The largest we have seen was collected in Persia by the late Mr. W. K. LOFTUS, and is three inches long and an inch and a half in diameter." The two sentences quoted appear to comprise all that has hitherto been written on the subject of the present paper.

25. A portion of Mr. LOFTUS's geological collection was presented, some time after his decease, to the Museum of the Natural History Society in Newcastle; and finding amongst other things a number of examples of this supposed *Alveolina*, I asked, and readily obtained, permission of the Committee to make such preparations from them as might be requisite for the elucidation of their structure.

26. A very slight examination by means of transparent sections convinced me that, notwithstanding a general similarity in external contour, the internal structure was distinct in many important characters from either of the previously known genera of fusiform FORAMINIFERA. In *Alveolina* the shell-wall is opaque, homogeneous, and Porcellanous; in

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* Mr. LOFTUS's collections were made in the years 1849–52, during the progress of a Joint Commission appointed by the English, Russian, Turkish, and Persian Governments for the demarkation of the Turko-Persian Frontier.

† "On the Geology of Portions of the Turko-Persian Frontier and Districts adjoining," by WILLIAM KENNETT LOFTUS, Esq., F.G.S., in Quart. Journ. Geol. Soc. Lond., August 1855, vol. xi.; foot-note, p. 285.

‡ Annals and Mag. Nat. Hist., Ser. 3, vol. v. (1860), p. 182.

Fusulina it is Hyaline and perforate; whilst in the specimens under consideration it was found to be of distinctly granular texture, resembling the built-up 'tests' of some of the smoother Arenaceous types. The obvious conclusion was that these singular fossils were widely separated in organization from their supposed congeners, and that they belonged to a new type, which probably bore a similar relation to *Alveolina* and *Fusulina*, that *Trochammina* (*incerta*) bears to *Cornuspira* and *Spirillina*. At the suggestion of my friend and colleague Professor T. RUPERT JONES, I propose the generic term LOFTUSIA for the type, thereby to associate with it the name of its discoverer, my lamented predecessor as Secretary to the Natural History Society of Northumberland and Durham.

27. *External Characters.*—Most if not all of the specimens of *Loftusia* that have been brought to this country, bear evidence of having formed part of a hard, compact, Limestone rock, from which they have been separated with the utmost difficulty. Indeed the process of mineralization in the animal remains, seems to have gone on simultaneously with changes in the physical character of the calcareous marl of which the matrix was originally composed; and the whole has been converted into a uniform subcrystalline mass, resembling some of the "fossil-marbles" of our Carboniferous system, and capable, like them, of receiving a high polish. The rock is traversed by irregular veins of white crystalline carbonate of lime, very similar to the material that has displaced the sarcode in the chambers and cellular portions of the shells. A piece of the limestone with the fossils *in situ* in the Newcastle Collection (Plate LXXVII. fig. 1) shows the condition in which they are found. It has apparently been long exposed to the action of weather, and is thereby a good deal roughened; but still it shows how large a proportion of the rock is composed of Organic Remains, chiefly those of *Loftusia*; and the course which the fracture has taken, right through the fossils at whatever angle they happened to lie, without deviating to follow either their periphery or any of their structural lines, indicates the determined adhesion which exists between them and the matrix. The appearance of the specimens that have been roughly separated on the spot, testifies to the same fact; for scarcely any of them show an exterior surface that can be regarded as satisfactorily representing the shell during the life of the animal. The general external features, however, are readily made out; and we are in no worse position in respect to this, than we were with the analogous genus *Fusulina*, which until a year or two ago was only known from the sections of Limestone in which it occurred; yet the recent discovery of specimens in a free state has done little beyond confirming the accuracy of the conclusions previously arrived at*.

28. In shape the specimens are all oblong or oval; but they vary considerably in their proportionate dimensions. Many of the longer ones taper almost to a point at either extremity (Plate LXXVII. fig. 2); whilst a stouter variety (fig. 3) exhibits obtuse

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* [Mr. BRADY here refers to the results I have recently obtained from the examination of specimens of *Fusulina* kindly transmitted to me by Mr. C. A. WHITE, of Iowa, U.S.; which results conclusively establish the correctness of the opinion I had founded on the study of less perfectly preserved specimens, that *Fusulina* belongs to the Vitreous or perforated series, instead of ranking with *Alveolina* (as was supposed by Messrs. PARKER and T. RUPERT JONES) in the Porcellanous or imperforate series.—W. B. C.]

rounded ends and a much shorter conjugate axis. The two largest perfect examples that have come under my notice* have about the same weight (three ounces); and their dimensions represent fairly, and in by no means an extreme light, the difference in proportion alluded to. Their measurements are respectively 3¼ inches by 1 inch, and 2¼ inches by 1¼ inch. In other words, the proportions between the axis and the transverse diameter are in the long form as 65 to 20, in the short thick variety as 36 to 20. In both of these specimens the transverse section is circular; and others of the same form have proportionate dimensions ranging between the two. There are, however, some few in which the transverse section is not circular but lenticular (bi-convex). These are of smaller size, and resemble an almond in general contour (fig. 4); but whether the peculiarity is the result of compression, or is due to an inequilateral plan of growth, is not easily determined. I am inclined to attribute it, for reasons which will presently be given, to the former cause; the more so as there is no ground for specific or even varietal distinction in the structure of the interior. It may be remarked in passing, that a similar or even wider range of variation in external form exists in the isomorphous genus *Alveolina*. In that group may be found every gradation in shape, from a nearly perfect sphere to a spindle with pointed ends, having a length four or five times as great as its thickness through the centre. Exceptional specimens of *Alveolina*, analogous to the compressed examples of *Loftusia* above referred to, are occasionally though rarely to be met with in Tertiary limestones.

29. As might be expected from the nature of the matrix, the exact condition of the exterior of the test, in respect to inequalities of the surface, ornamentation, or markings determined by structural peculiarities, is not very readily learnt. One or two of the specimens which appear to have been enucleated with less disturbance of the superficial layers than the rest, have a series of tolerably regular furrows, nearly equidistant, traversing the shell from end to end, somewhat resembling the uncut portion of that figured in Plate LXXVIII., though more uniform. These depressions are not so sharply defined nor so deeply excavated as similar lines in the smaller *Alveolinæ*, neither have they the same structural significance. It seems probable that they indicate only alternating periods of more and less vigorous growth, or that they are dependent on external circumstances. Arenaceous Foraminifera generally show but little tendency to the surface-ornamentation common in the Vitreous and Porcellaneous groups; and there is no reason to suppose that, in the living condition, *Loftusia* differed materially in superficial texture from *Trochammina*. Apart from the longitudinal riblets before described, the exterior may have been either quite smooth or slightly granular, according to the nature of the sand of which it happened to be built up, and the proportion of calcareous material which formed the cement.

30. *Internal Structure.*—Although, in general contour, *Loftusia* most closely resembles

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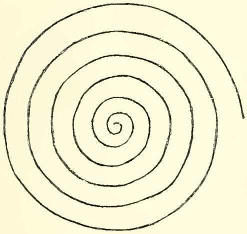
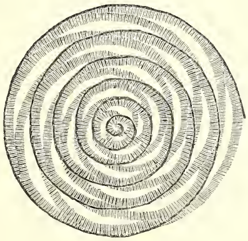
* A specimen in the Museum of the Geological Society, London, must originally have been somewhat larger than either of these; but, as it has had sections cut from it for microscopic examination, its exact dimensions cannot now be obtained.

the two genera already mentioned, *Alveolina* and *Fusulina*, its structural relations may be best understood by reference to the lower members of the Rotalian series, such as *Planorbulina* or *Discorbina*, or to the still simpler type *Involutina*. This relationship, though at first sight it may appear far-fetched, becomes obvious upon a comparison of their various sections. It is only necessary to imagine one of the simple Rotalians thickened and drawn out at the umbilici, so that what was before a convex disk should become a cylinder tapering more or less towards the ends; and the analogy is at once apparent. The transverse section of a body so constructed would correspond to the horizontal section of the original disk; and the ideal diagram B would represent equally well the arrangement of the principal chambers in the Rotalian types and in *Loftusia*, as seen in section. At the same time, the lines indicating the septa have in some respects a different significance in different cases. In theory the test of *Loftusia* may be said to consist primarily of a continuous lamina coiled upon itself, like a scroll constricted at the ends. The space enclosed by this 'primary lamina' is divided into chambers by longitudinal septa. The septa are of 'secondary' growth; that is to say, they are not continuous with the principal wall or 'spiral lamina,' but are rather offshoots from it. The chambers separated by the septa are long and very narrow, and extend from one end of the shell to the other. The septa are not perpendicular to the 'spiral lamina' as in *Alveolina*, but very oblique; and they often take also a more or less oblique direction longitudinally. The longitudinal section is in this way somewhat confused, and less to be relied upon than the transverse, in its bearing upon the form and relation of the various parts. The chambers are further divided by numerous irregular extensions of the secondary or septal system, which it may be convenient to regard as subordinate to the rest. These 'tertiary' ingrowths are generally at right angles to the septa, or nearly so.—The diagrams A, B, and C will make somewhat clearer the general plan of structure; but it must be borne in mind that they are purely ideal, and drawn without reference to scale. The first of the three, A, may be supposed to represent a transverse section of the spiral lamina, or 'primary' wall; B shows, in addition, the 'secondary' system to which the septa belong; whilst C indicates roughly the subdivision of chambers by the 'tertiary' ingrowths.

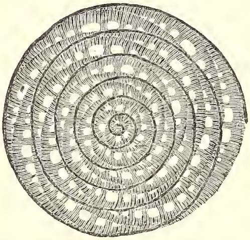
A.



B.



C.



31. We must now consider these various structures *seriatim*, in relation to the appear-

ances presented by the actual specimens. The process of infiltration, which has in every instance extended to every part of the organism, has obscured its most important peculiarities. Fortunately in the discovery of *Parkeria*, and in the results of Dr. CARPENTER'S researches on this new and most interesting type of FORAMINIFERA, we find a clue to the reading of several portions that would otherwise have remained unintelligible. Many of the specimens of *Parkeria* are completely infiltrated with a subcrystalline mineral, very similar in physical characters to that occurring in the chambers of *Loftusia*. But there are others, which, either from the nature of the matrix, or from the compact texture of the peripheral layer of the test, contain no such deposit; but remain, as nearly as can be judged, in the state of a dead and empty recent shell. In addition to these, a few examples of *Parkeria* have been met with partially infiltrated; only their exterior layers having been consolidated by mineral deposit. Each of these three sets of specimens has added its quota to the facts upon which the elucidation of a somewhat complex organization depends; and each has a distinct value in the study of *Loftusia*. By comparing the appearance of corresponding portions of the infiltrated and uninfiltrated test in *Parkeria*, reliable data are obtained from which to estimate the condition of *Loftusia* prior to the filling up of its cavities with inorganic matter. Constant comparison with the less altered type has been found needful, in order to demonstrate the organization of the more obscure form; and for the opportunity of pursuing the subject in this way I am indebted to the kindness of Dr. CARPENTER.

32. The texture of the 'test' has been stated to be Arenaceous, that is, built up of sand-grains held together by a structureless calcareous cement. It is only necessary to refer to it in this place, in so far as it affects the relation of the walls to the sarcode-cavities. The granules vary considerably in size, but are comparatively much larger than those from which the investment of *Parkeria* is formed; hence in the transparent sections of *Loftusia* the texture does not appear so homogeneous, nor is the outline of the labyrinthic ingrowths so well defined; indeed it is obvious that in the recent condition the interior surfaces could not have had the same smooth finish that is to be observed in the open portions ('interspaces') of *Parkeria*.

33. After careful examination of a large number of sections of *Loftusia*, made on the median line in both a transverse and a longitudinal direction, I find no indication of the existence of a central cavity, or anything resembling the large primordial chamber which is so usual a character amongst the FORAMINIFERA. The tendency to fill up the interior of the chambers with shelly ingrowths, which leads to some of the most striking peculiarities of its organization, is manifest from the very earliest period of life. We have no very young specimens from which to study the condition of the test before it assumes the form and habit of maturity, except such rare instances as may be found in microscopical sections of the limestone matrix, and these are far from satisfactory. One section of the rock, figured at Plate LXXVIII. fig. 5, shows, however, amongst other minute fossils, the transverse section of what I have little doubt is a very young *Loftusia* (*a*). The whole is about $\frac{1}{45}$ in. in diameter, and shows the space enclosed by the first turn of the spiral lamina, and about half the circuit of the layer immediately surrounding it.

The spiral lamina itself has much the same dense opacity as is presented by older individuals; and the interior has, so far as can be made out, a loose, arenaceous texture, which, with a further deposit of cementing material, might be expected to give the sort of structure we find at the axis of the mature shell. But in the absence of evidence from specimens in the intermediate stages, much importance cannot be attached to the characters of a single individual, the original features of which may have been greatly altered in the process of fossilization.

34. In the fully grown examples, the first circuit of the 'spiral lamina' encloses a space of variable dimensions,—in some cases measuring from $\frac{1}{30}$ to $\frac{1}{25}$ inch in diameter at the centre, and from $\frac{1}{8}$ to $\frac{1}{4}$ inch in length, more or less; and the revolutions succeed each other with tolerable regularity at intervals of $\frac{1}{50}$ to $\frac{1}{30}$ inch. From twelve to twenty revolutions are usually found in an adult specimen; but twenty-five have been noticed in one instance, and doubtless even a larger number may occasionally be met with.

35. The 'spiral lamina' or 'primary skeleton,' as it may be regarded, is composed of almost impalpable calcareous grains closely cemented. It is imperforate, and not more than from $\frac{1}{1000}$ to $\frac{1}{800}$ of an inch in thickness. From this extreme tenuity it necessarily depends for support upon accessory structures.

36. The space enclosed by its first revolution—constituting the central axis (Plate LXXX. fig. 2, *c a*)—is occupied by a mass of shell-substance somewhat resembling in general features a piece of fine sponge, but not quite uniform in its structure. Quite in the centre it assumes the form of a network of irregular anastomosing tubes, with the interspaces filled in with shell-substance to a greater or less extent; but nearer the primary lamina, the irregularly disposed growths resolve themselves into a more definite series, and take a uniform direction. The outer portion becomes in fact the commencement of a system of parallel columnar or tubular processes springing from the inner surface of the spiral lamina, and having their free ends directed inwards (Plate LXXIX. fig. 1, *a*, and fig. 2, *a*). This system of parallel tubuli may under favourable circumstances be traced throughout the course of the spiral lamina, except when interrupted by the occurrence of septa; and it forms, as well shown in the figures just referred to, a sort of lining to its inner surface. The two structures are in such close juxtaposition that they appear continuous; and their physiological distinctness is only noticed in exceptional places, when a minute portion of the sarcode appears to have become entangled between them, leaving for a short distance the primary lamina free from the accessory skeleton (Plate LXXIX. fig. 2, *b*, and Plate LXXX. fig. 3, *b*). The nature and extent of the labyrinthic portion of the layers may be best understood from a longitudinal section taken on a line very near the periphery, as shown in Plate LXXIX. fig. 1; for whilst a central section presents all the layers in the same aspect, one taken near the exterior bears a different relation to each consecutive layer. Thus we have about the centre of the figure at *c* the transverse section of the parallel processes just described as lining the spiral lamina; whilst at *a* is seen the lateral aspect of the same. Such a section leaves no doubt as to the tubular character of even the more compact portions of the labyrinthic system.

37. The septa, which divide the space enclosed by the spiral lamina into chambers, are directly connected with the labyrinthic system, and form a part of the accessory skeleton. There is no continuation of the primary lamina as an imperforate facing to them, nor is there any analogous investing organ. The septa are therefore entirely secondary, and are merely extensions of the labyrinthic system, at regular intervals; taking a very oblique direction, and terminating on the outer surface of the preceding whorl. The end of the shell, where, from the greater depth of the layers, and the gradual thinning out of the chambers, the septa form a prominent feature, shows most clearly their cancellated structure and the sort of connexion that exists amongst them. A magnified drawing of this region (Plate LXXIX. fig. 3) bears a strong general resemblance to those portions of *Parkeria* in which the 'radial tubes' are largely developed, though differing in several essential characters. Not only are the cancellated structures of the septa connected, but there is free communication between the adjacent chambers of the same layer. In other words, whilst the spiral lamina is imperforate, the septa have numerous perforations which allow the passage of sarcode-stolons.

38. But neither the cancellated structure immediately lining the primary lamina, nor its septal developments, can be distinguished in any very definite manner from further ingrowths of subordinate importance, which to a greater or less extent occupy the interior of the chambers. These 'tertiary' extensions are of very irregular contour; and being usually built up of the coarsest particles, are less easily made out.

39. Thus whilst the 'primary skeleton,' or what may be regarded as such, is simple and easily understood, the accessory structures are of somewhat complex character, and present appearances very diverse in different specimens, not only from the variable extent to which they are developed, but also in their disposition and texture. Some specimens show scarcely any traces of the accessory skeleton, beyond that already indicated as lining the spiral lamina and forming the septa; whilst there are others in which the sarcode-cavities are to a great degree filled up by its extension into their interior; but in either case some portions of the superadded structure in each chamber are prolonged, until they rest upon its floor. In those specimens which have their cavities least filled up, the ingrowths take the form of tubular columns, which traverse the chambers in a radial direction (*i. e.* perpendicular to the spiral lamina), terminating either on the septum of the previous chamber, or on the exterior wall of the preceding whorl of chambers. In others they are more massive and irregular, and appear to be arranged so as to subdivide the chambers in an incomplete manner into chamberlets. When this latter condition exists, the intersection of the chambers does not take place at regular intervals; but the wide central portion of each is left comparatively open, and the ingrowths increase in frequency as the sides thin out. Transverse sections of the larger specimens present to the naked eye an appearance as of dark spots set at very regular intervals along the spiral band, which on examination are found to indicate the central larger chamberlets in the successive chambers; that is, the wider portions have the fewest intersecting shelly growths. The smaller chamberlets at each side are hardly to

be distinguished, unless magnified, in the general labyrinthic system. This distinction of large and small subdivisions is one of degree only, and is not nearly so striking under the microscope as might have been expected from the appearances presented to the unassisted eye; but it nevertheless does exist, and is a means to an end.

40. The 'accessory skeleton' in *Loftusia* may be regarded as the homologue of the labyrinthic lamellæ in *Parkeria*; although there are important differences, the precise significance of which it is impossible to explain with our present limited knowledge of the relation of the two types. The most remarkable of these is that in *Loftusia* the labyrinthic portions take their rise from the inner surface of the primary spiral lamina, and are directed inwards, that is, towards the central axis; whilst in *Parkeria* the order is reversed, the corresponding structures presenting their free ends towards the periphery. Again, the 'radial tubes' which complicate the labyrinthic system in *Parkeria*, have no precise analogy to any portion of the accessory skeleton of *Loftusia*; the nearest approach to anything of the sort being the lines of tubular communication between the septa of the individual layers, at the ends of the shell, where the layer is thickest; but here, as in other parts, the spiral lamina cuts off direct communication between the layers. The office fulfilled by the accessory skeleton in *Loftusia* is, I conceive, simply that of a support to the primary lamina, imparting the necessary solidity to the organism. The subdivision of the chambers into chamberlets seems to be an accidental circumstance, and has but little bearing on the general economy of the animal.

41. In considering its fitness for this purpose, the various external relations of the organism must be borne in mind. It is manifest that the delicate calcareous lamina, described as the 'primary wall,' would, both from its contour and extreme tenuity, be utterly insufficient of itself to protect a mass of sarcode three inches long and one inch in diameter, or to impart that rigidity which, judging from other examples, is necessary to animals of its class.

42. The layer immediately within the 'primary wall' adds greatly to its strength, not only from the additional thickness it imparts, but also from the connexion its septal prolongations establish between the successive whorls. This portion, however, does not represent a solid mass; and the septal portions are further weakened by irregular perforations for the stoloniferous tubes connecting the sarcode of the adjacent chambers. The columnar extensions of the shell-substance provide direct vertical support; and their distribution on the plan described is that likely to ensure the maximum of strength combined with economy of material. A longitudinal section whose direction nearly coincides with the long axis of the chambers (Plate LXXX. fig. 4), shows the primary walls as parallel lines, and the septa (*s*, *s*) as slightly oblique bands diverging in the most gradual way, and eventually connecting one wall with the other. In the exaggerated view so obtained, the columnar supports (*ts*, *ts*) appear at regular intervals; and throughout the long narrow ends of the chambers they are very close and massive in proportion to the space left for sarcode. As the chamber widens, they diminish in frequency and proportionate dimensions.

43. The tubular condition of the principal part of the secondary skeleton has been inferred from the appearances presented by portions of exceptional specimens in which the infiltration has least obscured the structure. But in the absence of these, there would have been sufficient evidence to be gained from a close comparison with corresponding appearances in *Parkeria*, to demonstrate the general tubularity of the labyrinthic system. This character is foreshadowed in a group of Foraminifera of much simpler type. I have elsewhere* described the occurrence in *Ellipsoidina* (an interesting genus of Foraminifera discovered by Professor SEGUENZA in the Miocene clays of Sicily) of a line of tubular columns, whose only ostensible office is to support a series of chambers which otherwise would have but little connexion with each other. There is a strong reason why the accessory skeleton which forms so large a proportion of the entire bulk of the shell in *Loftusia* should be built up on a plan that would ensure the greatest strength with the least weight. The habit of Foraminifera is to live on the surface of the sand or mud at the bottom of the sea, and recent shells taken from a position entirely beneath the top of the mud are dead and empty;—in point of fact the animal dies if it is buried in the sand. It is clear from the nature of the limestone matrix, that the floor of the sea in which *Loftusia* lived was a very fine calcareous mud, soft and oozy. Now the specific gravity of the material of which the skeleton is built is about 2·7; and sarcode itself may be regarded as but little heavier than water; so that if, as may be supposed, the hollow sinuses were occupied by sarcode, it would materially alter the relation between the specific gravity of the animal and the element in which it lived; that is to say, the mass comprising the shell and the sarcode would be of much lower specific gravity than would be the case were the skeleton solid:—hence the animal would be correspondingly better fitted to preserve its natural habitat. It is not certain, however, that the labyrinthic sinuses were occupied by sarcode, or even that the ends projecting into the sarcode-cavities were open; and it is still possible that they may have fulfilled some distinct functional purpose. In the absence of evidence on this point, it is needless to dwell upon it; but it is within the range of possibility that the cancellated structure may during life have formed a sort of water-system, or perhaps may even have been filled in part with air. These are but surmises that have presented themselves during the investigation; but if either condition existed, it would further reduce the general specific gravity.

44. *Physical and Chemical Relations.*—The condition of this fossil is very unfavourable for the determination of the elementary physical characters of the original organism, owing to the completeness of the mineralizing process to which it has been subjected. The sand of which the test is formed is entirely Calcareous; and its identity in chemical composition with the mineral substance occupying the sarcode-cavities renders it impossible to separate or distinguish the two by means of reagents. We learn also from the study of the different condition in which specimens of *Parkeria* have been found, that the infiltration of a substance having the same chemical composition as the test has a

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* Annals and Magazine of Natural History, 4 ser. vol. i. p. 333, pl. xiii.

much greater effect in obliterating its structural characters, and even in obscuring their outlines, than the same process when a different material is concerned. Thus the Calcareous test of *Parkeria* becomes almost devoid of character when its cavities are filled with a subcrystalline calcareous mineral; whilst a specimen having its chambers occupied by silex has lost none of its distinctive characters. Chemical analysis of the infiltrated fossil (*Loftusia*) shows that at least 99 per cent. consists of Carbonate of Calcium, the remaining 1 per cent. being chiefly siliceous matter, a composition representing equally well an average sample of the limestone matrix. The test, therefore, is built up of Calcareous sand-grains, incorporated by a cement of carbonate of calcium. But although the selective power which seems traceable in some Arenaceous Foraminifera, enabling them to choose certain sand-grains in preference to others*, has no exercise in respect to the chemical nature of the constituents of the test, there is still something of the same sort observable in relation to the *size* and *distribution* of the particles which go to its formation. Thus whilst the septa and the looser portions of the labyrinthic structures are coarsely arenaceous, the spiral lamina is composed of exceedingly minute particles. The presence of a number of specimens of the smaller species of Foraminifera imbedded by accident with the sand in which they were living, and now forming a portion of the fabric (Plate LXXX. fig. 3, *f*, *f*), renders it comparatively easy to estimate the size of the sand-grains. The largest that could be satisfactorily measured was about $\frac{1}{100}$ of an inch in diameter; but they seldom attain more than one half this size. Specimens of the same species abounding in the Limestone matrix run to much larger dimensions. One of the almond-shaped specimens of *Loftusia* which appears to have had its walls somewhat disintegrated by pressure or otherwise, presents its constituent granules in a very uniform condition, both as to their general appearance and their dimensions, and in this instance the average diameter is about $\frac{1}{400}$ of an inch. In the more compact portions of the labyrinthic system, the granules are smaller; and as they approach the spiral lamina they become still more minute. In the thin layer which constitutes the lamina itself, a magnifying-power of 500 diameters (the highest I have been able to use with advantage on any section yet prepared) shows the ultimate structure only as a uniform, densely packed mass of particles, individually too small for even approximate measurement. The transparent sections (Plate LXXIX. figs. 4 & 5) cross regions in which the constituent granules are exceptionally small and uniform, and show well their close setting in the compact portions (*sg*, *sg*).

45. The variable external appearance of such of the fossils as have been exposed—through the unequal action of the weather, especially on the fractured surfaces—is pro-

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* The question of selection of materials amongst Foraminifera with composite tests is one to which my attention was drawn in a recent chemical examination of subarenaceous *Miliolæ* (*Quinqueloculina agglutinans*) obtained by Mr. Jeffreys from deep water in the Hebrides. Their tests were clearly formed of sand-grains and cement. They occurred in siliceous sand, having but a very small percentage of calcareous matter derived from the *débris* of Molluscan and other shells; yet they were entirely soluble in very weak acid, leaving scarcely a microscopic trace of silica.

bably due to other causes rather than to the size of the constituent sand-grains, and chiefly to two, viz. a slight difference in the character of the subcrystalline deposit in the chambers, and the partial disintegration of the shell-structure from pressure or other disturbing cause, during, or it may be previous to, the process of mineralization. I have noticed that the specimens in which the exposed portions are the roughest and most granular, are those in which the structure is most confused, not merely in the labyrinthic growths, which are naturally of coarser texture, but even in the compactly built spiral lamina, which, usually so well defined, is often scarcely traceable in such individuals.

46. It has been stated that the shells of a number of the minuter forms of Foraminifera are to be found imbedded in the shelly material forming the test, their presence being due to the fact of their having been living amongst the sand in the neighbourhood of the animal whilst the process of building its skeleton was being carried on. Their identification is of considerable importance, as they afford, together with the organisms to be observed in the limestone matrix, the only data by which the depth of water wherein the animal lived, may be indicated with any degree of accuracy. In the test itself the following have been noticed: in many cases it is impossible to do more than identify the Genus, specific and varietal characters often depending on peculiarities not to be recognized in sections.

Biloculina ringens, Lamk.
Biloculina contraria, D'Orb.
Triloculina oblonga, Montagu.
Triloculina trigonula, Lamk.
Triloculina tricarinata, D'Orb.
Quinqueloculina seminulum, Linn.
Spiroloculina planulata, D'Orb.
Trochammina incerta, D'Orb.
Planularia longa, Cornuel.
Textularia sagittula, Defrance.
Textularia variabilis, Will.
Textularia pygmæa, D'Orb.
Bigenerina nodosaria, D'Orb.
Discorbina, sp.
Rotalia Beccarii, Linn.

The specimens seen in the limestone rock are generally of much larger size than those which have been built into the walls of *Loftusia* itself. Most of the foregoing varieties occur, and, in addition, the following,—

Spiroloculina canaliculata, Czjzek.
Valvulina Austriaca, D'Orb.
Cristellaria, sp.
Dentalina, sp.
Bulimina ovata, D'Orb.
Planorbulina ammonoides, D'Orb.
Rotalia Schrœteriana, P. & J.
Nummulina, sp.

The last named is one of the small thick forms characteristic of the lower Tertiary strata.

47. Mr. W. K. Parker has given me much assistance in these determinations. The conclusions to be derived from them are that the rock is a lower Tertiary limestone, very similar to some of our Miliolite limestones, but richer in the small arenaceous forms;

and that the sea-bottom was a soft calcareous mud, and lay at a depth of from ninety to one hundred fathoms. A few minute fragments of Molluscan shells resembling columns of *Pinna*, and small pieces of fossil Polyzoa, are the only remains that are to be found of animals of higher organization than Foraminifera.

48. *Zoological Relations.*—From the details of structure which have been adduced, the genus *Loftusia* would seem to find a natural place at the head of the Arenaceous series of Foraminifera, a position corresponding to *Alveolina* in the Porcellanous group, and *Fusulina* amongst the Vitreous forms. In texture it is similar to the higher *Trochamminæ.* Its general plan, in so far as the primary skeleton is concerned, is simple; and there is no approach to the more complex organization found in the shell of the Nummulite or its immediate allies. Its most striking external difference from the other members of the Arenaceous group (*Parkeria* of course excepted) is its *size*; and the chief peculiarity of its internal structure consists in the secondary shelly growths necessary for the support of the enlarged test.

49. Notwithstanding great diversity in the size and contour of the specimens, their difference is attributable to degree of development depending on external causes, rather than to specific or varietal distinction; and with a slight reservation in respect to the compressed specimens, I propose to place all under one species, of which the following will serve as a description.

Loftusia, gen. nov.

Testâ liberâ, regulariter rotundatâ, axe elongato; transversè sectâ orbiculari (aut lenticulari?); ex spirâ bene compositâ, cujus orbis quisque orbem antecedentem penitus amplectitur, constante; in numerosissimos loculos septis longitudinalibus partitâ iterum plus minusve subdivisos; structurâ arenaceâ; aperturis (multis, complexis, labyrintheis?).

L. Persica, spec. nov. L. *testâ elongatâ, ovatâ vel fusiformi; transversè sectâ orbiculari (vel compressâ?); extremitatibus obtusis aut rotundatis; loculis multis, angustis, interne cancellatis, cancellis ad axem versis; septis perobliquis; aperturis (multis, complexis, super facie ultimi loculi arcuatâ sparsis?); superficie lævigatâ aut subarenaceâ, interdum sulcis subtilibus paribus intervallis inter se distributis in longitudinem sculptâ. Longa,* 1·5 *usque ad* 3·5 *poll. Lata* ·5 *usque ad* 1·25 *poll. Loc. Persia, fossilis.*

Distribution.—In respect to distribution but little can be said beyond what appears in Mr. Loftus's Memoir (*op. cit.*, p. 235) and the notes accompanying the specimens presented to the British Museum and the Geological Society; but the information from these sources is deficient both in Geographical and in Geological details. In describing the geological characters of a section lying "on the direct road between Káláh Túl and Isfáhán," after speaking of a confused series of gypsiferous rocks, which seem "as if the bed had been shot off the side of Mererárí during its sudden elevation," the author adds, "Masses of gravel-conglomerate lie in the bed of the stream and high up the slopes of the mountain through which the Ab-í-Bázúft flows," and then follows this foot-note:—"A few miles N.E. of this stream (but before reaching the left bank of the Kúran at Dú Púlún) I procured from a hard rock of blue marly limestone a gigantic species of *Alveolina*, three inches in length." The station appended to the specimens in the British Museum and the Geological Society is the "Kellapstun Pass, near Dú Pulún, Bakhtiyari Mountains, Persia." Unfortunately scarcely any of the names mentioned appear on the "Sketch-map" that accompanies the paper; and for scientific purposes the district referred to may be said to be as yet unmapped. I am indebted to Mr. KEITH JOHNSTON, of Edinburgh, for a detailed tracing of the region, procured with some pains from unpublished German sources; from which it appears that Dú Púlún is on the 32° parallel N. Lat., and that a Longitude of 50° 30 E. would indicate a point halfway between it and the little mountain stream Ab-í-Bázúft. The district lies between the N.E. corner of the Persian Gulf and Isfáhán.

50. Our knowledge of the Geological distribution of the type may be summed up in few words. Mr. LOFTUS appears to regard the "blue marly limestone" as belonging to the oldest Tertiary rocks, though he does not say so very distinctly; and the evidence of the Foraminifera imbedded in it leads pretty conclusively to the same view. The data afforded by the Microzoa are probably sufficient confirmation, in the absence of any satisfactory record of larger fossils from the same geological horizon.

In conclusion I have to express the obligation I am under to my friends Mr. W. K. PARKER and Dr. CARPENTER, for the interest they have taken in the subject of the present paper;—to both for suggestions derived from their large knowledge and philosophic views in connexion with the Protozoa generally,—to the latter for light thrown upon obscure points by the study of collateral structures in *Parkeria*, and above all for the opportunity of constant reference to specimens of that genus, without which the history now given could not have been so far elaborated.

EXPLANATION OF THE PLATES OF LOFTUSIA.

PLATE LXXVII.

Fig. 1. Piece of *Loftusia*-limestone, the surface of which has been 'weathered' by exposure, and the sections of the fossils thereby brought into relief (*natural size*).

Figs. 2, 3 & 4. *Loftusia Persica* (*natural size*). Of these figs. 2 & 3 represent longer and shorter individuals of the normal form, whilst fig. 4 is the compressed variety with lenticular transverse section described in § 27. Figs. 2^a, 3^a, 4^a represent the transverse sections of the three specimens drawn to their natural size.

Fig. 5. Section of the Limestone rock forming the matrix of *Loftusia*, with Foraminifera *in sitû*.

a. Young specimen of *Loftusia* cut transversely, showing the space enclosed by the first turn of the spiral lamina, and about half the circuit of the layer immediately surrounding it.

Sections of several other Foraminifera included in the matrix are seen.

PLATE LXXVIII.

General view of the structure of *Loftusia*, showing the appearances of sections cut on different planes, and their relation to each other.—Magnified about 4 diameters.

PLATE LXXIX.

Fig. 1. Longitudinal section of *Loftusia*, very near the periphery, viewed as an opake object.—Magnified 45 diameters.

s l. Imperforate primary skeleton or spiral lamina.

a. Series of parallel, columnar, secondary shell structure, immediately lining the primary lamina.

c. The same cut transversely.

It must be borne in mind that this is not a central section, but a tangential one cut so near the periphery that the direction of the section differs in its relation to each successive layer, so as to illustrate fully the arrangement of the accessory skeleton. The centre, representing the innermost of the four layers of which portions are drawn, shows at *c* the appearance presented by the parallel columnar shelly processes (*a*, *a*) when cut across. The portion of the figure to the right exhibits a mass of the accessory skeleton formed from overlapping septa, and shows the sort of intercommunication between them. Owing to the direction of the section, or possibly to accidental causes, the spiral lamina (*s l*), the continuity of which is usually a prominent character, appears lost at the end of the layers to the right, though well seen in the other portions of the specimen.

Fig. 2. A portion of a transverse section. *s l* represents the spiral lamina, and at *b* its distinctness from the accessory structures may be noticed. This condition may be found at points in almost every specimen. The nature of the septa, as prolongations of the series of columnar processes (*a*, *a*, *a*) lining the primary lamina, may be easily traced. The subdivision into chamberlets, a large chamberlet (*c c*, *c c*, *c c*) occupying the centre of each chamber (see § 39), is also apparent.—Magnified 45 diameters.

Fig. 3. Longitudinal section of a portion of a layer near the end of the central axis. At this point, where the layer is widest and the chambers thin out and overlap, the intercommunication of the septa is often so regular and complete that it resembles very strongly the portions of *Parkeria* in which the system of radial tubes is most developed.

Figs. 4 & 5. Transparent sections, to illustrate the nature of the subcrystalline calcareous deposit filling the chambers, and the close setting of the sand-grains (*s g*, *s g*) in the compact portions of the test.—Magnified 45 diameters.

PLATE LXXX.

Fig. 1. General view of a transverse section of an average specimen, mounted in Canada balsam and seen as a transparent object, under a low power.—Magnified 5 diameters.

Fig. 2. A similar preparation from one of the compressed specimens alluded to at § 28. —Magnified 6 diameters.

All the almond-shaped specimens are small, possibly not fully grown; and if so, the composite test may have been less consolidated than in mature individuals. This may account for their form. The arrows *l f*, *l f* indicate a line on which pressure at the two sides appears to have caused the fracture of many of the layers.

Fig. 3. Enlarged view of a portion of the transparent section shown in fig. 1.—Magnified 25 diameters.

s l, *s l*. Spiral lamina.

b, *b*. Points at which the 'primary' and the 'accessory' skeleton are not in close approximation, and show their distinctness.

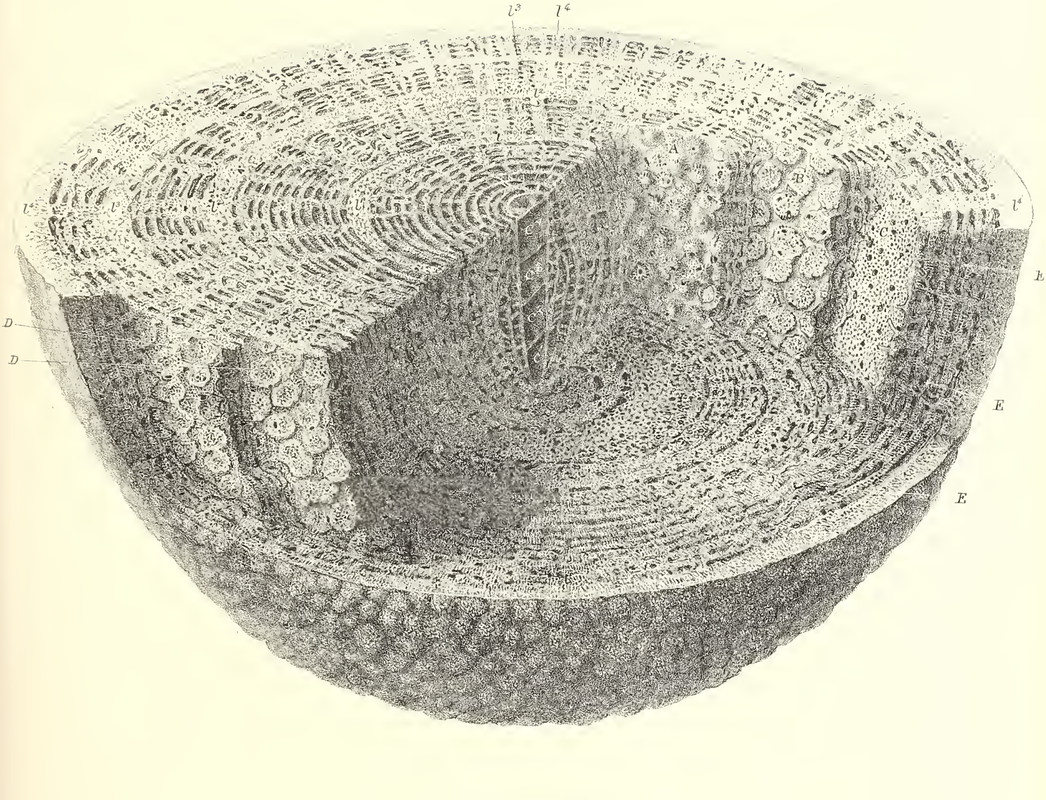
f, *f*, *f*. Imbedded Foraminifera *in sitû.*

Fig. 4. Longitudinal central section of a single layer near the periphery, showing the regularity of 'tertiary' processes subdividing the chambers.

s l, *s l*. Primary skeleton.

s, *s*. Septa.

t, *s*. Tertiary shelly processes affording perpendicular support.



PARKERIA.

A. Hollick del. et lith.

W. West imp.

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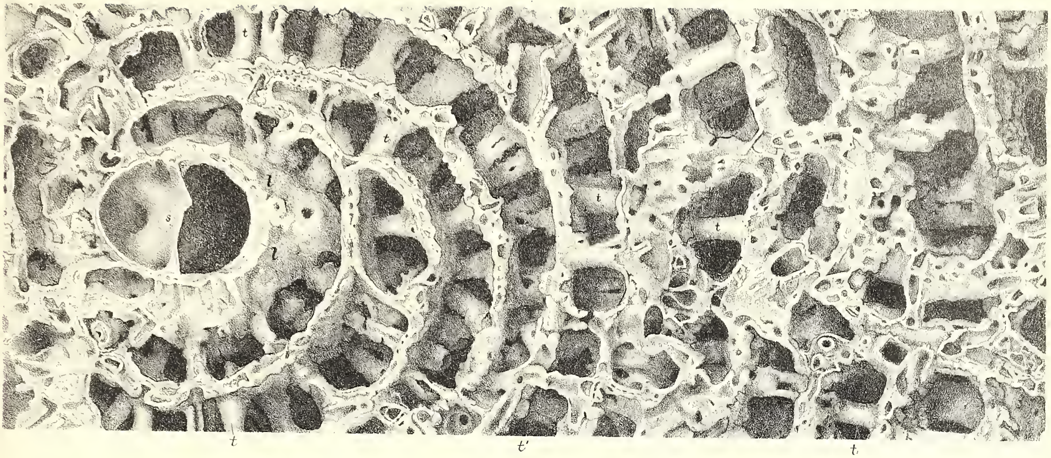

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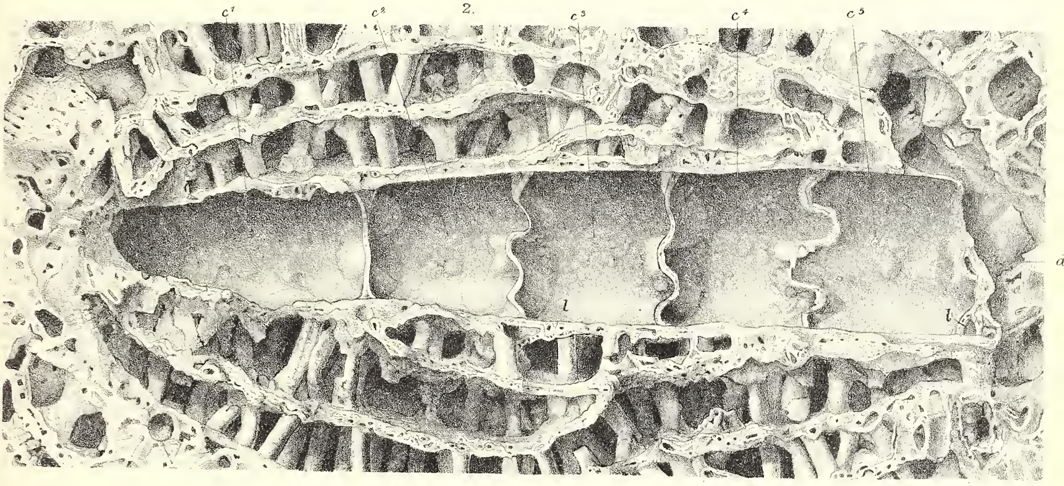

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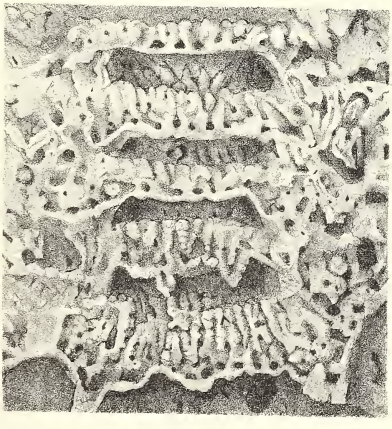

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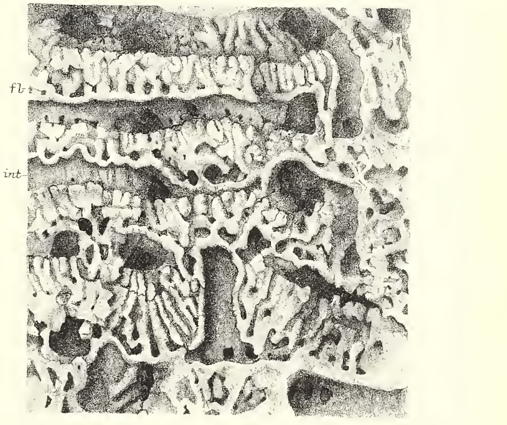

A. Hollick del. et lith.

W. West imp.

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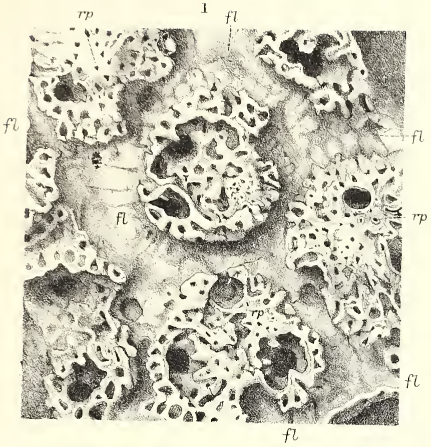

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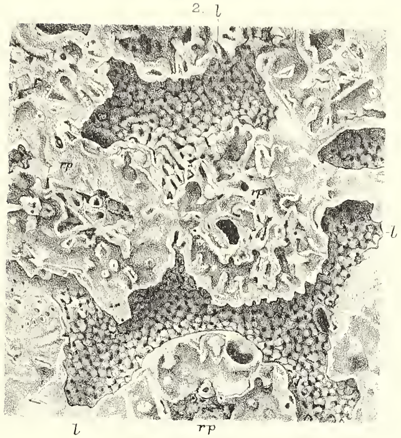

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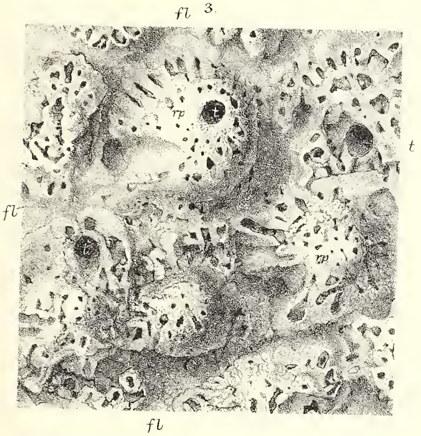

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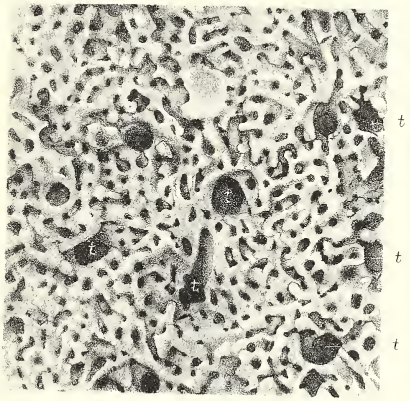

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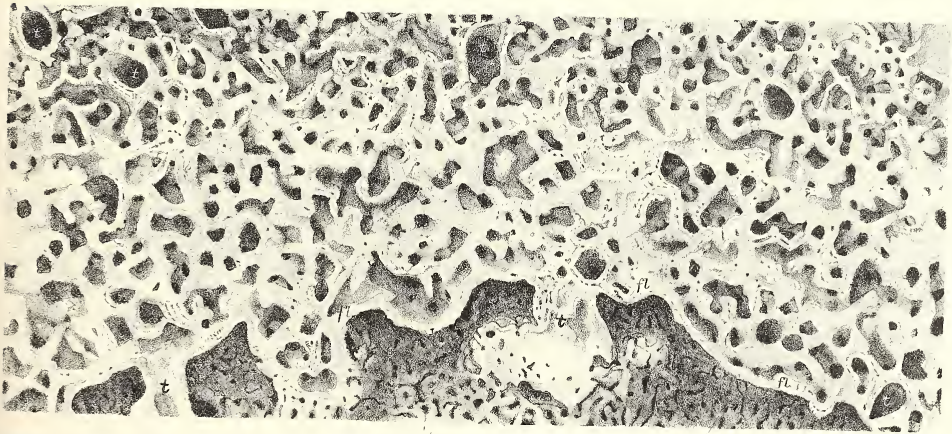

A. Hollick del et lith.

W West imp.

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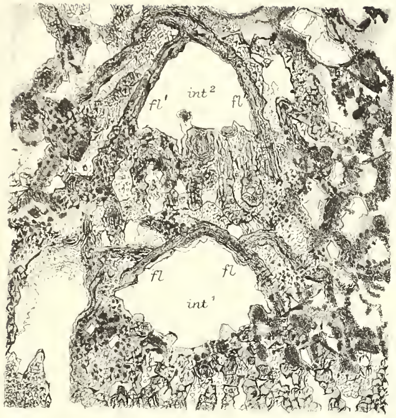

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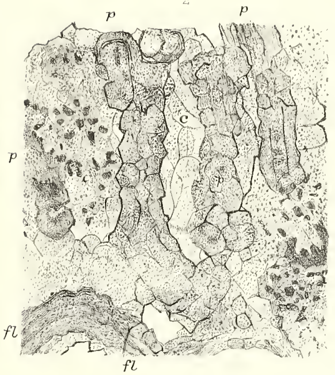

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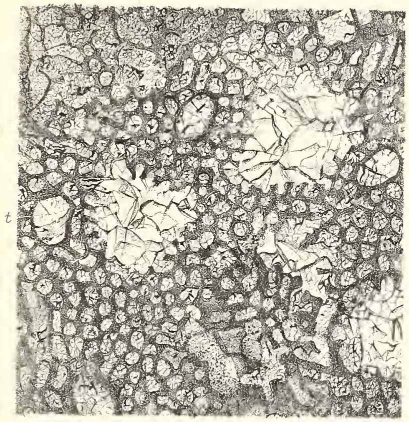

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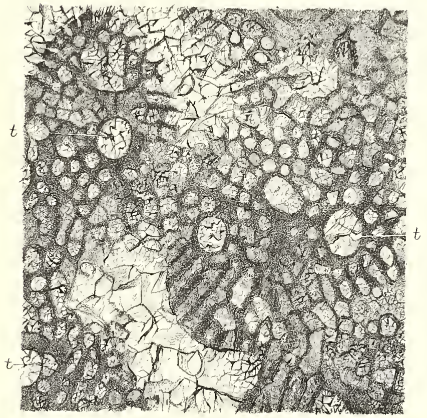

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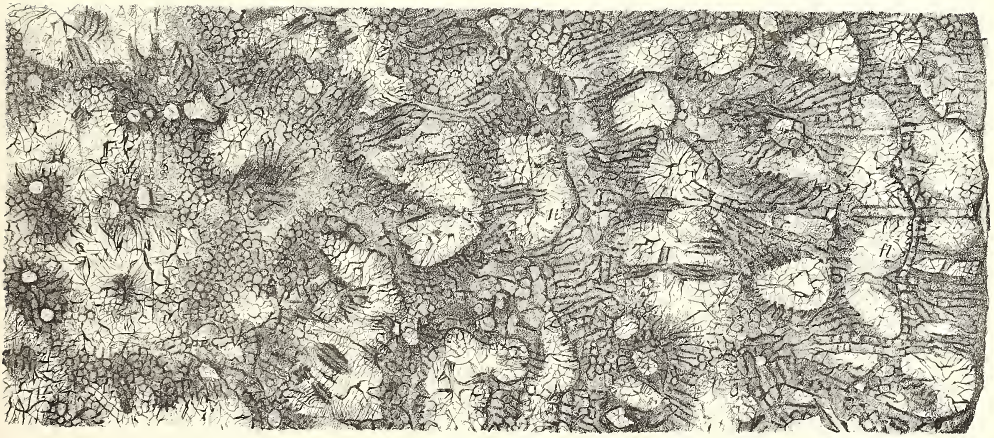

A Hollick del. et lith.
W West imp

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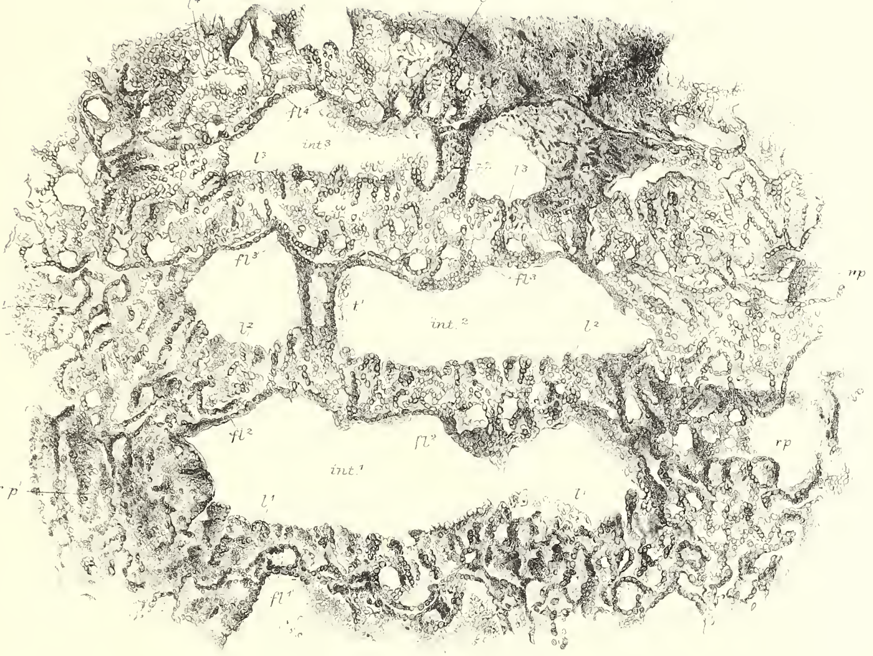

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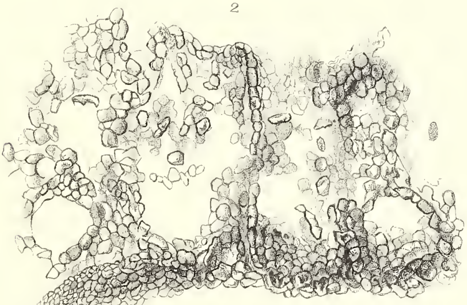

W.H. Wesley lith.

W West imp

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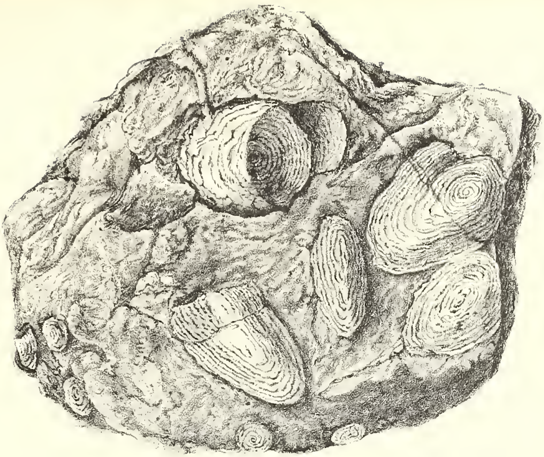

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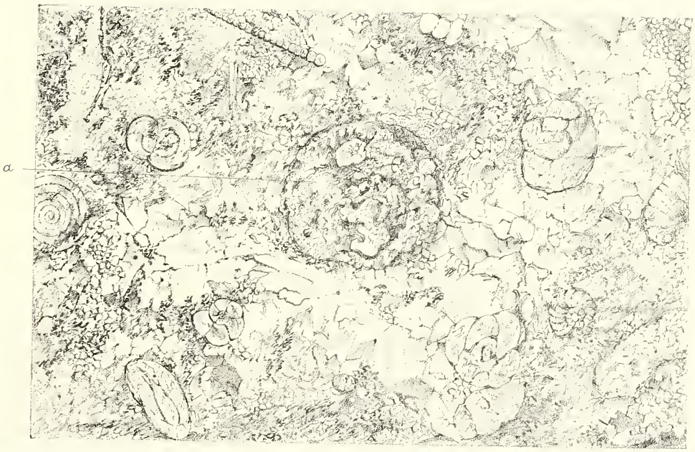

Tuffen West del. et lith. W. West imp.

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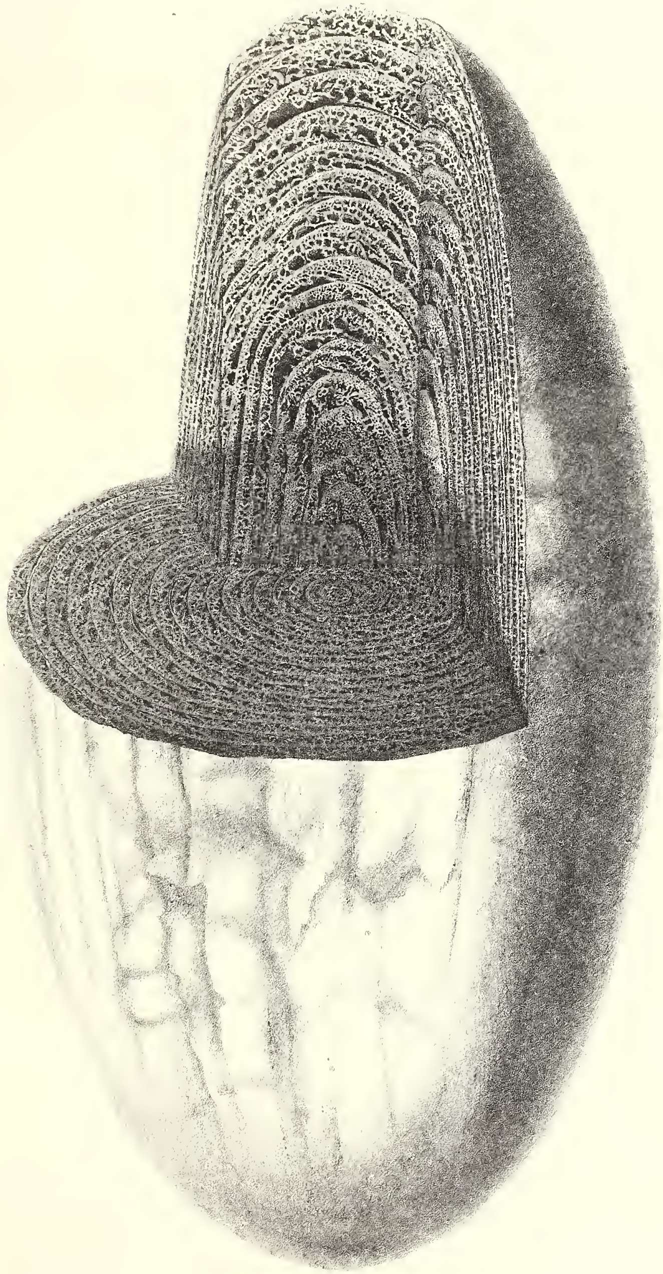

LOFTUSIA PERSICA.

A. Hollick del. et lith.

W. West imp.

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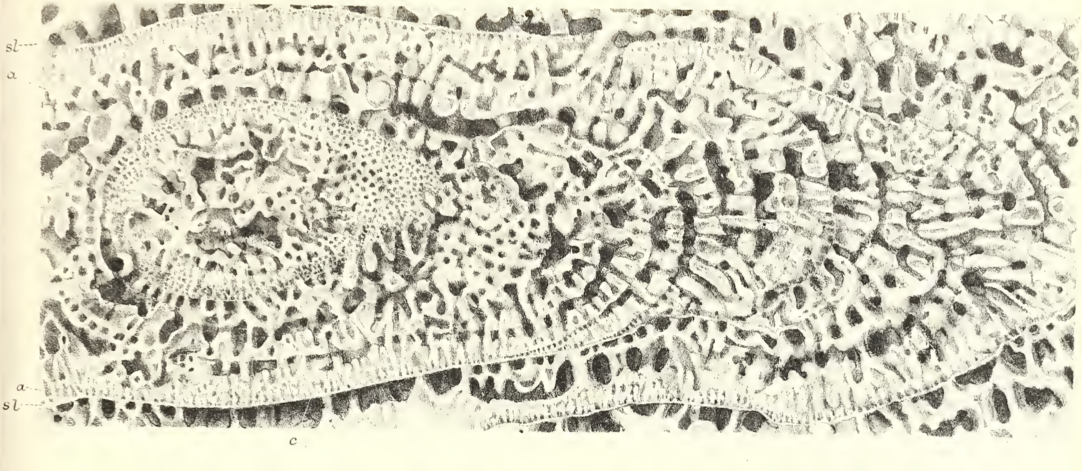

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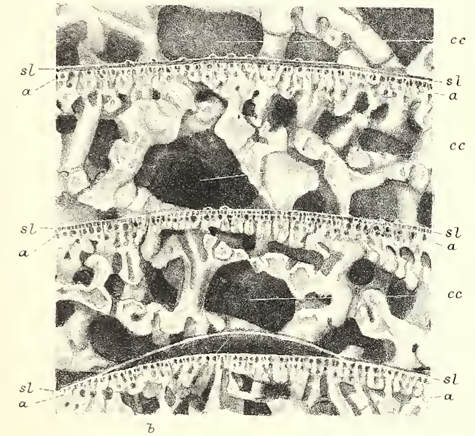

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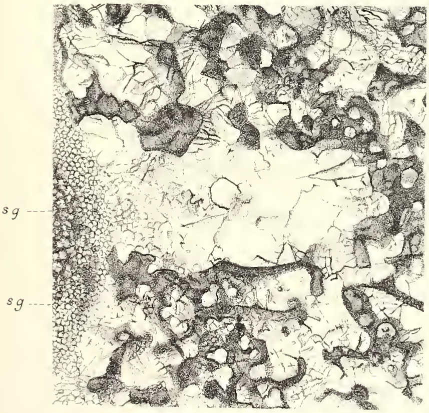

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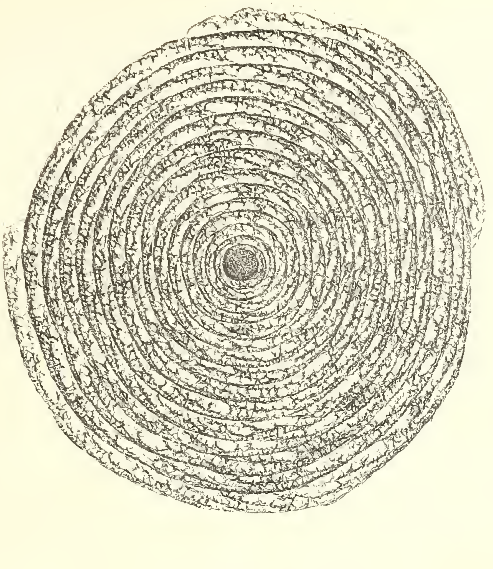

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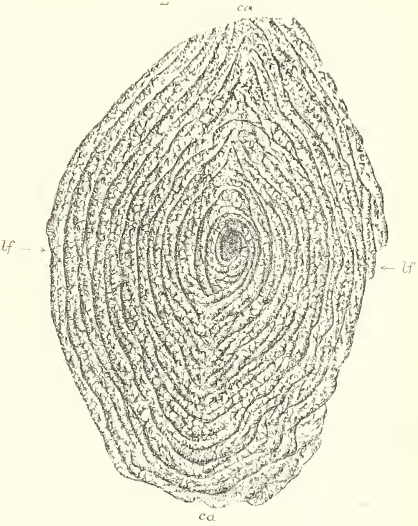

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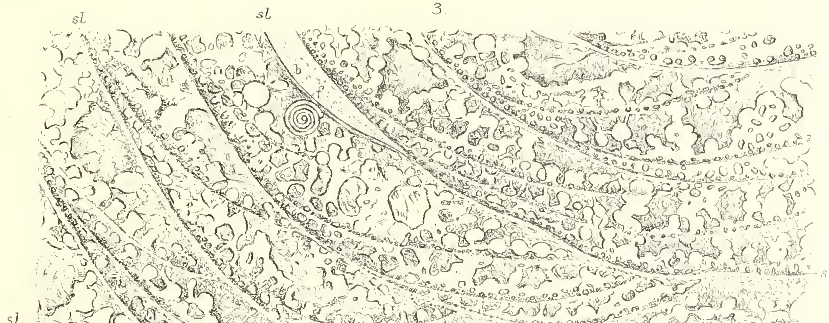

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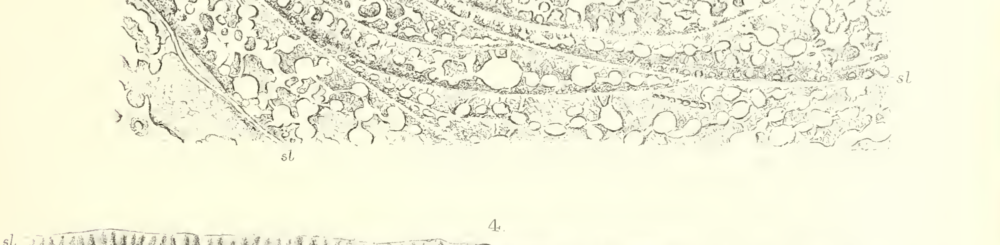

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W West imp.

BRITISH MUSEUM NATURAL HISTORY.

XXIX. *On the Structure and Development of the Skull of the Common Fowl* (Gallus domesticus). *By* WILLIAM KITCHEN PARKER, *F.R.S.*

Received November 25, 1868.—Read February 11, 1869.

Introductory Remarks.

IN my former paper, which treated of the structure and development of the skull in the Ostrich-tribe*, I proposed to write a series of such papers on the skull of the Vertebrata, and that the first of these should be confined to that of the Common Fowl.

This Bird is selected for several reasons, the first of which is the readiness with which it may be obtained; but, as far as science is concerned, a still more important reason lies in the fact that it not only forms a good halfway subject between the Ostrich and the Singing-bird, but, in a wider survey, it serves as an excellent stand-point from which to look backward to the Fish, and forward to the higher Mammalian forms.

The present paper is much more special than the last, which treated of the skull of several kinds of Struthious Birds, in just as many stages as I was able to obtain: this time an essay has been made to describe, step by step, the whole process of growth of the skull, face, and sense-capsules from the fourth day of incubation to extreme old age.

My reason for not describing the earliest stages is, that I find it done to hand already; and although I have repeatedly verified the observations of other authors on the primary condition of these parts, yet I have nothing more to add to what is already known. The latest and best description that I have seen of the primordial condition of the head of the chick is to be found in Professor HUXLEY'S 'Elements of Comparative Anatomy,' pp. 136–142, and figs. 57 A–G.

My starting-point is at that stage which is the last but one in Professor HUXLEY'S series—namely, figs. 57 F and F′ (p. 138); my second stage agrees with his fig. 57 G.

In describing the Struthious skull, I did not depend merely upon what an examination of those types revealed, but had already made a large number of observations (and drawings) on the development of the skull in various Families of Birds, and also in many types from the other Vertebrate Classes. It was shown me, however, by my most judicious friend, Professor HUXLEY, that my work missed its end, in some degree, from its diffuseness, and that it would be better to get a perfect history of one type of skull, than an imperfect knowledge of any number whatever. So, to be thorough, it must content me to cultivate a small and modest plot at one time, trusting in the Unity of Nature for the value of the results, and confident that, if I can read the meaning of the Fowl's skull, my eyes will be opened to see very much more, below, above, and around.

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* Philosophical Transactions, 1866, vol. clvi. part 1. pp. 113–183, pls. 7–15.

There will be now a necessity for some modification of the nomenclature used in the former paper, both with regard to the tissues and the various morphological regions; for in both these departments of my work I trust there has been some extension of knowledge, as well as rectification of former errors.

The ossific process, than which nothing is more confusing to the morphologist, has of late received a more definite nomenclature (see 'On the Shoulder-girdle and Sternum,' Ray Soc. 1868, p. 4); the new terms will be used here. These are:—(1) "ectostosis," for that tract of osseous deposit which is formed between the perichondrium and the cartilaginous mass; (2) "endostosis," for that deposit which takes place primarily in the intercellular substance of hyaline cartilage, or between the cells of simple cartilage; and (3) "parostosis," for all ossifications of mere fibrous tracts. In the paper 'On the Shoulder-girdle' (p. 10) I have spoken of a modification of the growth-process in the Warm-blooded Classes, which, until fairly understood, cost me much perplexing thought; this is where a parosteal patch of bony matter *grafts* itself upon a cartilaginous plate, setting up, first, an ectosteal deposit close upon the cartilage-mass, and then an endosteal process between the cells themselves. In this case we have the coexistence of the three types of "ostosis" to form a single osseous centre; and this state of things, so different from what is seen in the Cold-blooded Classes, and by no means to be confounded with after-coalescence, must be looked upon as a very important metamorphic modification in the skeleton of the higher types*.

As far as I can see at present, an explanation of this deliquescence, as it were, of the histological process in the formation of bone will greatly smooth the difficulties that have hitherto stood in the way of the homological part of this science; it will thus be seen that nothing is more unsafe than hasty decision upon representative parts in the various types.

There is much to be done in the study of cartilage with regard to morphological regions, and their comparison in the various types; for in some cases differentiation and chondrification are synchronous, and, in a sense, synonymous; whilst in others the fission of the cartilage does not take place until it is thoroughly consistent and even dense. This after-splitting may be perfect, or more or less imperfect; in the latter case a cartilaginous plate becomes *notched* in some instances, and *fenestrate* in others (see 'Shoulder-girdle and Sternum,' p. 4).

But as hyaline cartilage is merely to be considered a consolidated primordial cell-mass, and a very fast-growing tissue also, it is not surprising to find it running riot over a large number of morphological territories (*op. cit.* p. 4): this takes place to the greatest extent in the lowest and most generalized types, which, however large (even gigantic) they may become, are nevertheless mere embryos throughout life, in respect of their morphological development.

The sharp distinction between the skull and the vertebræ is well seen in this—that

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* In the Amphibia no definite line can be drawn between parastoses and ectostoses, and the most typical endosteal deposit is merely an ossification of that part of the fibrous laminæ which immediately encloses the cartilage.

whilst the whole of the notochordal region of the skull belongs to the occiput, this region, if it had suffered fission, would have sufficed to form a whole series of vertebræ. Thus that cranial region which has most of the vertebral nature in it cannot answer to one actual vertebral segment, seeing that it contains (subjected to the law of a new type of growth) several potential segments.

As the skull proper cannot be shown to conform to the vertebral column, so neither can the facial arches be put into the same category with the ribs; for the present they must wait until their development has been worked out perfectly in a considerable number of Vertebrate types: I mention this to excuse myself from all controversy concerning them in the present communication. The mouth and the fauces (the faucial region is of great extent in the Cyclostomous Fishes) are hedged in by what are evidently one class of cartilages; these may be either free rods or fenestrate plates: I propose to call these the "facio-faucial" skeleton.

These bars extend beyond the skull, and are very variably attached to it—in some of the lowest Vertebrates (as the Cyclostomi, the Chimæroids, and the Lepidosiren) being, anteriorly, mere outgrowths of the skull, whilst in the higher Classes they have a very independent development. In the Bird there are only three poststomal arches developed, whilst in the gill-bearing "Ichthyopsida" there are several.

It seemed to me to be necessary to preface the description that is to follow with these remarks; but I must now let the Bird's head tell its own tale. What there may be in this account which will not harmonize with the descriptions given in the former paper will be duly noted from time to time, and the reasons for a modified nomenclature will be given.

Structure of the Chick's Skull, First Stage.—Head of Embryo 3 lines long: 4th Day of Incubation.

The appearance of the chick's head and face on the 4th day, as seen from below, is well shown in Professor HUXLEY'S figure (*op. cit.* p. 139, fig. 57 F); another figure (F′) shows the cartilaginous cranium of the same. In Plate LXXXI. figs. 1 & 2, I have given what appears to me to be the state of things at this early stage; fig. 1, however, the lower view, is somewhat diagrammatic, as I have in it anticipated the differentiation of the pterygo-palatine bar (*p.g.pa.*) from the next stage; these show the parts as magnified 9 diameters.

The visceral clefts (Plate LXXXI. fig. 1, $_{1, 2, 3}$) are still evident; and the fronto-nasal process (*f.n.*) is, as yet, free at its sides, so that the anterior nares (*n.*) are still mere clefts—the foremost or prestomal clefts. The great mouth-cleft (*m.*) is four-sided, with concave sides and produced angles; and the anterior angles run into the nasal clefts: these clefts, and their intervening arches, all evidently belong to one category; the arches surround, and the clefts open into the oro-faucial cavity.

To show the character of the skull-floor, a chick's head at this stage has been sliced completely through, horizontally (fig. 2), the second and third cerebral vesicles have been completely removed, and the first vesicle, the subdividing rudiment of the hemispheres, has had its upper half removed; the lower half of each eyeball is shown also *in situ.*

The notochord (*n.c.*) is seen to be half the length of the head, or a line and a half, and to reach within a very slight distance of the pituitary space (*p.t.s.*): this *relative* but not *real* retreat of the notochord now bespeaks the first appearance of the post-pituitary part of the basisphenoidal region. The notochord is clubbed at its fore end, it then is narrower, then thicker between the auditory sacs (*c.l.*), and is again somewhat diminished as it passes into the atlantal region.

The broad, thick plate of cartilage (shown as somewhat sliced away, horizontally, above the cochlear cavities, *c.l.*, in the figure) which lies right and left of the notochord, is the "investing mass" (*i.v.*) of RATHKE*. At this stage the "investing mass" is rapidly passing from simple cartilage into the solid hyaline variety; it is most dense nearest the notochord, and becomes more and more gelatinous as it is traced upwards into the wall of the cranium. Hence the commencement of the spinal chord is not as yet bridged over by a cartilaginous superoccipital plate, and the cartilage in which the upper part of the auditory sacs are imbedded is still in a soft condition. Here it may be at once remarked that no separate cartilaginous auditory capsule is formed in the chick (such as can be plainly seen in the Tadpole), but the two moieties of the investing mass grow into one continuous "occipito-otic" cartilage†. At a small distance in front of the cochlear cavity (*c.l.*) the investing mass is suddenly narrowed: this is where the fifth nerve passes out; and this nerve divides the occipito-otic region from the posterior sphenoidal. At most, the clubbed anterior end of the notochord is wedged into the very end of the basisphenoidal region; and afterwards it will be seen that the whole of its cranial portion becomes the axis of the basioccipital. All the nerves between the fifth cranial and the first spinal are related to the investing mass; so that even if it were ceded that the occipital region is essentially vertebral in its nature, yet it must then be looked upon, not as one segment, but the non-segmented counterpart of several. On each side of the end of the notochord the investing mass at first grows outwards in an angular manner (shown in Professor HUXLEY's fig. 57 F′, and in Plate LXXXI. fig. 2, *l.g.*); these angles are the rudiments of the cartilaginous "lingulæ sphenoidales;" these parts arise from the *roots of the trabeculæ*‡.

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* RATHKE's account of this part, in his work on the Snake (Entwickelungsgeschichte der Natter, 1839), is thoroughly correct; I will give it as translated by Professor HUXLEY (Croon. Lect. p. 56, and Elem. Comp. Anat. p. 237):—"The differences between the basis of the skull and the vertebral column in the earliest embryonic condition are:—(1) That, round that part of the notochord which belongs to the head, more of the blastema, that is to be applied in the spinal column to the formation of the vertebræ and their different ligaments, is aggregated than around the rest of its extent; and (2) that this mass grows out beyond the notochord to form the cranial trabeculæ."

† The periotic mass, which becomes perfectly segmented from the occipital sclerotome in many Mammals—but in them only in the last or osseous stage of growth—is never cloven in any degree from its surroundings in the Fowl; it is, however, partially cloven off in many Water-birds, by a fenestra which appears between the epiotic and the lower edge of the superoccipital.

‡ I think that RATHKE's term "middle trabecula" may be dropped; it appears to me to be merely the gelatinous precursor of the "posterior clinoid wall," and has nothing in common with the basal paired trabeculæ. —See HUXLEY's Croon. Lect. p. 57.

The trabecular roots are transversely crested (the somewhat diagrammatic figure 2 shows this but feebly); this is the angle of that bend formed by the early skull called the "cranial flexure" (Huxley, Elem. p. 137).

This crest becomes very large, and is persistent, notwithstanding the after-straightening of the cranio-facial axis; it is connected with the high "posterior clinoid wall." The anterior, smaller moiety of the cranio-facial axis is bent, first at an acute, and afterwards at an obtuse angle; it is becoming obtuse on the fourth day; all this fore part is formed by the "paired trabeculæ:" these are flat bands of, at present, soft or simple cartilage; they are now about $\frac{1}{100}$ of an inch in width, and are moderately thick in proportion. These bands are gently curved outwards at first, to enclose an elegantly ovoidal membranous space, the pituitary space (Plate LXXXI. fig. 2, *tr.*, *p.t.s.*); this space is enclosed by the early coalescence of the symmetrical bands in front of it; and this coalesced part is nearly equal in length to the pituitary region. The trabeculæ maintain a similar size to their extremities, but at their coalesced part they have begun to form an arched outgrowth on each side; these symmetrical expansions are the rudiments of the "aliethmoidal" and "aliseptal" cartilages of the nasal labyrinth. This broadened ethmoidal part of the trabeculæ is bent backwards in a rounded manner on itself, so that the remaining part of the trabeculæ lies on a lower plane, parallel with the pituitary floor, and with the free ends looking directly backwards (Plate LXXXI. fig. 1, *c.tr.*); the free ends are slightly divergent, and are separated by a space about equal to their own width. These free retral ends of the trabeculæ are the "trabecular horns;" they form the soft skeleton of the "fronto-nasal lamina" (*f.n.*), and are developed into the "alæ nasi" or "alinasal laminæ," and do not coalesce to form the intermaxillary axis or "prenasal cartilage," as I once supposed (see former paper, pp. 121 & 122). The "fronto-nasal laminæ" will have united with the "maxillary rudiment" (*m.r.*) to enclose the anterior nares (*n.*) before the "intermaxillary axis" will be evident: this will be described in the next stage. Here one may pause to remark that the nasal labyrinth is formed continuously with the primordial cranium, just as is the case with the otic capsule; any segmentation that may appear afterwards will thus be a secondary morphological process; and thus the eyeballs are sharply distinguished from the other sense-capsules, which, from their undefined skeletal growth, and their relations to the visceral arches, form a most puzzling problem to the morphologist. It will be seen from this description that the "anterior sphenoidal region" is scarcely at all represented at this stage; for the somewhat narrowed waist formed by the trabeculæ immediately in front of the pituitary body is all that has yet appeared of the "anterior clinoids," the prepituitary part of the basisphenoid, and the presphenoid. This latter part is, indeed, feebly represented in the adult Bird, and only occupies an angular space above the junction of the perpendicular ethmoid with the basisphenoid. At present there is a curved, clubbed, subocular bar, the "maxillary rudiment" (*m.r.*), which comes very close at its anterior clubbed end to the "fronto-nasal lamina," but has not yet united with it to enclose the anterior nares (*n.*). In fig. 1 the cartilaginous differentiation of the pith of this bar, my study of which has been from fine transverse sections in the next stage, is somewhat anticipated. The axis of this soft bar is converted into the palatal and pterygoid rods (*pa.*, *p.g.*); and from the outer edge of each of these bent clubs a lamina grows downwards (see HUXLEY, *op. cit.* fig. 57 G, *l.*), in the internal fibrous stroma of which the maxillary and jugal bones are afterwards formed. The axis of the maxillary rudiment never has any cartilaginous connexion, anteriorly, in the Bird, with the ethmoidal lamina (prefrontal); and, behind, the chondrification of the pterygoid portion of this axis is quite distinct from, and much later than, that of the "quadrate." Here we see that the "subocular arch" is much modified from what is seen in the Ichthyopsida.

The primordial skull figured by Professor HUXLEY (fig. 57 F) must have been from a less mature embryo than that which I am here illustrating as my first stage; for in that figure the quadrate (*qu.*) is shown as continuous with the antero-external part of the "investing mass." In my specimen (Plate LXXXI. figs. 1 & 2, *qu.*) the quadrate is already a very distinct tuberous mass of consistent cartilage, rapidly becoming hyaline. MECKEL'S cartilage (*m.k.*) is also very distinct and solid, and its articular end has a sinuous face, answering to that on the lower end of the quadrate; whilst the posterior and internal angular outgrowths have already appeared (fig. 1, *m.k.*). These Meckelian rods are very short in proportion to their thickness, are gently curved forwards, and nearly meet at the mid line by rounded ends. These axial parts of the first pair of poststomal laminæ are surrounded by very delicate blastema—the parent tissue of the splints, muscles, and skin of the lower jaw; the outline of this primordial mandible is emarginate at the mid line. That which is perhaps the most noteworthy in the first poststomal arch at this stage is its position with regard to the auditory capsule; its pier, the quadrate, is segmented from the antero-external angle of the investing mass, directly in front of the periotic capsule, and opposite the junction of the anterior with the middle third of the cranial part of the notochord; whilst the fifth nerve (5) passes out in front of it. This normal position is lost and then regained before the chick is ripe. Close behind the quadrate there is the first poststomal cleft (1), ready to become converted into the complex tympanic cavity.

In the obtuse angle formed by the Meckelian rods, and lying on a higher plane than those rods, we find the distal arrested cartilages that belong to the second poststomal arch; these are the "cerato-" and "basi-hyals" (Plate LXXXI. fig. 1, *c.h.*, *b.h.*). At present these are merely thickened masses of blastema, their outline being somewhat indistinct, as the young cells of which they are composed are not sharply separated from the formative substance which will become their perichondrial investment. The cerato-hyals (*c.h.*) are even now only half the size of the mandibular rods; but this is the greatest *relative* size they attain, for they diminish much afterwards.

There is no proper skeletal substance between the top of the cerato-hyals and the tissue that forms the auditory "columella" (stapes): this latter part is not differentiated sufficiently to be described at present; it is both *late* in appearance, and also very minute.

The basi-hyal (*b.h.*), although formed in the united edges of symmetrical laminæ, is, even as a defined mass of thickened blastema, quite azygous; it is tear-shaped, the narrow end lying between the lower ends of the cerato-hyals; this basal part is better defined than the arches, and chondrifies first.

Behind the second fast-closing cleft (2) there is now to be seen a pair of well-defined rods, nearly as large as the Meckelian cartilages, and as early in their chondrification; these are the "branchials" (*c.br.*), answering to the first branchial arch of the Ichthyopsida. There is a less distinct upper piece, pointed and small (*e.br.*), and a delicate streak of ill-defined blastema behind and between (*b.br.*); this latter is formed into the long slender so-called uro-hyal, the counterpart of the "basibranchial band." Behind the branchial arch a chink still indicates the place of the third visceral cleft (3)*.

At this early stage the arch of the tongue has begun to lie *within* the mandibular arch, just as the lessened first branchial arch comes to lie within the massive hyoid arch in the Osseous Fish.

Already the third visceral arch of the Bird has outgrown the second—a state of things universal in the Class of Birds.

Before leaving this stage, it may be noted, as instructively parallel with that which is persistent in Cartilaginous Fishes, that there is no exo-skeleton, no præmaxillæ, maxillæ, dentaries, angulars, or the like; the mouth and unenclosed nostrils are entirely *below* the head: these, and the rudimentary tympanic cavities, open freely into each other, and are all lined with dermal tissue, which is, as it were, tucked in between the visceral laminæ from the outer surface of the head.

Second Stage.—Head of Embryo from 4 to 5½ lines long: 5th to 7th Days of Incubation.

In the course of twenty-four hours great changes have taken place in the chick's skull and face. In an embryo with a head 4 lines long (Plate LXXXI. fig. 3, 6 diam.), a vertical section shows the notochordal region to be shorter than that formed by the trabeculæ; and this anterior moiety of the cranio-facial axis has become much straighter, the head having now to a great extent recovered from the "cranial flexure." The "investing mass" has become more solid; and a distinct swelling on each side, posteriorly, shows how the occipital condyle (*o.c.*) is formed—very reptilian, however, in shape, at first. On each side, a thin soft lamina of cartilage (*e.o.*) is growing up behind the third cerebral vesicle (*c.v.* 3); this is the commencement of the occipital plane. At the angle formed by the bending of the primordial cranium upon itself, a transverse crest of cartilage has grown rapidly upwards and backwards; this, the "posterior clinoid wall," protects the pituitary body behind, and lies in the midst of a quantity of delicate stroma, which eventually becomes the fore part of the "tentorium cerebelli." The internal carotid artery (*i.c.*) is seen to be entering the skull in front of this wall.

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* Till lately I have partly followed Professor OWEN's nomenclature for the third poststomal arch of the Bird, calling its moieties "thyro-hyal." (See Brit. Assoc. "Report on Archetype," 1847, p. 295, fig. 23, where the lower piece is identified as the "hypobranchial" of the Fish, and the upper is called "cerato-branchial.") I find, however, that the "thyro-hyals" of the Batrachia and Mammalia are merely retral "hypobranchial" processes; and I cannot consider the lower piece in the Bird to be other than the "cerato-branchial."

The greater part of the investing mass may now be treated of as the basioccipital region (*b.o.*); anteriorly the nascent fibrous tissue is thickening below this part to become a bed for the deposit of the basitemporal.

The pituitary space is now much foreshortened, very deep, and is indicated in the figure by the entrance of the internal carotid artery (*i.c.*); the cartilage has become high, even below and between the optic nerves (2); and close in front of the pituitary body the anterior clinoid ridge (*a.cl.*) has commenced. But in front of the optic nerves the greatest and most sudden change has taken place, the very short broad waist between the pituitary space and the rudimentary ethmoidal alæ shown in fig. 2 being at this stage greatly elongated and altogether developed into a high crest: this is the ethmo-presphenoidal plate (*p.sp.*, *eth.*). This plate, which is rapidly passing into hyaline cartilage, is somewhat higher behind than before, is nearly straight above, is oblique behind, above the optic nerves, concave below, and has a gently convex margin in front.

The alæ of the nasal labyrinth are not shown in this section; but above and below the line where these have been cut away on the left side, two projections are seen. The upper of these is the retral spike, in which the ethmoid ends behind above the olfactory crura*; whilst the lower process is one of the greatest importance in the morphology of the face, it being the prenasal or snout-cartilage (*p.n.*). This part, which is the endoskeletal axis of the premaxillary region, grows at first *backwards* as well as downwards, having the same direction as the "fronto-nasal lamina," and being an azygous outgrowth from the crest which forms between the trabecular cornua—the rudimentary septum nasi, continuous with the ethmo-presphenoidal plate. The cornua themselves, as I have already asserted, develope themselves into the alæ nasi. This condition of the prenasal cartilage is like what is seen in the ripe embryo of the Green Turtle (*Chelone mydas*); in that animal, however, it is less rounded in shape, and projects further downwards, forming a soft core to the premaxillaries†. The thick arcuate inferior edge of the ethmo-presphenoidal plate has already begun to be underlain by that fibrous stroma which afterwards thickens very much between the basis cranii and palatal skin to form a nidus for the rostral part of the "parasphenoid."

Below, and on each side of the basis cranii, the maxillary rudiment has begun to send downwards the facial lamina in which the maxillary and jugal bones are afterwards developed, and to have a more distinct rod on the inner side, which becomes the palatine (*pa.*) and the pterygoid (*p.g.*); but this will be best studied in a chick a day or two older. I shall also leave the mandibular (*m.k.*) and hyoid cartilages (*h.*) for description from an older embryo.

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* This spike is called "crista galli" (*cr.g.*) in my former paper; but Professor Huxley has shown me recently that there is nothing in the Bird which answers to that plate, save that notched and grooved part of the perpendicular ethmoid which lies exactly between the olfactory nerves; so that, practically, it may be said to be undeveloped in this Class.

† Professor Huxley is strongly inclined to believe that the "trabeculæ," from their roots, are in reality the foremost (and of necessity the innermost) pair of visceral arches.

The development of the parts goes on very rapidly, so that when the head is 5 lines in length a much clearer idea of the structure of the parts can be obtained. A vertical section, left-hand of the septum, of such a skull is shown in Plate LXXXI. fig. 4, and a side view in fig. 5, both magnified 6 diameters; in these views the cerebral vesicles are not figured.

A low ornithic type, such as is persistent in the Ostrich, is now attained. I have already had to compare the skull of the chick with that of a Plagiostome and of a Turtle; after the Struthious stage has been passed, many of the higher ornithic specializations will rapidly appear.

The straightening of the cranio-facial axis has gone on so as to make the face much more prognathous; and the axis of the anterior part of the face (*p.n.*) is especially altered, so as to have already taken on an ornithic character; the boundary, also, between the nasal and orbital regions can now be seen. One landmark has become especially visible, on account of the denser condition of the cartilage; this is the bridge for the nasal nerve (*n.n.*): in the adult bird this is seen near the free postero-inferior angle of the nasal septum. For some distance behind this bridge the cartilage continues thicker than we find it between the eyeballs; the larger, thinner, posterior part of the cranio-facial axis answers to the whole of the presphenoid and the posterior or interorbital part of the perpendicular ethmoid. The grooves for the olfactory nerve (1) can be well seen; and the retral spike of the ethmoid surmounting the nerve-grooves has become much more defined, and has begun to take a backward direction instead of the vertical and *human* direction it had a day or two before (see Plate LXXXI. fig. 3, *eth.*). This is now the highest part of the cranio-facial axis, whereas the presphenoid was the highest in the last embryo. The whole base of the prepituitary part of the primordial skull is very thick and rounded; and its thickness from side to side increases in the prenasal cartilage (*p.n.*), which now shows itself to be a very fit model on which the premaxillaries of any type of Bird might be formed; in no Bird whatever, let the shape of its face be what it will, is the type of the first model or platform wholly lost, although in every case the primordial structure (into the type of which they were cast, as it were,) undergoes very early wasting. Between the palatal skin below, and the still very arcuate skull-base above, a considerable mass of stroma is formed, which is cordiform in section, and which soon becomes the seat of the rostral (or anterior parasphenoidal) ossification: this rostral stroma (*r.st.*) is shown in fig. 6, magnified 12 diameters. This tract is composed of thin-walled baggy cells, which never chondrify (except on the surface in certain birds, as the Psittacinæ and Ardeinæ), but develope either into bone (internally) or into periosteum (externally). In fig. 7 the differentiation of the tissues that underlie the skull-base in the posterior ethmoidal region is shown, magnified 160 diameters. The ethmoid (*eth.*) is already formed of ordinary hyaline cartilage, with abundant intercellular substance and tear-shaped cells; next below this is a tract of very delicate granular stroma (*gr.st.*), then a deep layer of the larger-celled young connective tissue (*r.st.*), and below this the epithelium of the palate (*ep.l.*). The aggregation of a thick bed of nascent fibrous tissue between the skull-base and the palate and fauces, and the conversion of the greater part of this mass into bone in a very early stage, is common to many of the Vertebrata—for instance, the Ganoid and Teleostean Fishes, the Amphibians and Ophidians; the Lizards show this structure much more feebly.

The thickened and solidified postpituitary part of the basis cranii shows this superfaucial mass—the seat of the "basitemporal" ossifications (Plate LXXXI. fig. 4, *bt.st.*); the fibrous layer thins out towards the occipital condyle.

The parts of the primordial skull can now be made out more clearly; the exoccipital lamina (*e.o.*) is growing upwards to meet its fellow in the superoccipital region (*s.o.*), and thus enclose the spinal chord.

Above the meatus internus (*m.i.*) the anterior semicircular canal is seen to bulge inwards and to grow backwards; below and behind the meatus is seen the eighth nerve (8), below and in front of it the cochlear elevation (*c.l.*) nearing the mid line. The low anterior clinoid elevation (*a.cl.*) and the high posterior clinoid wall (*p.cl.*) are well seen, and the notochord (*n.c.*) mounting up between the moieties of this wall, which now begin to coalesce across their middle; they do not unite, however, either above or below. A thin lobe of cartilage ascends the side wall of the skull outside and behind the posterior clinoid wall; this is the rudiment of the alisphenoid (*a.s.*); it is connected with the periotic capsule by a bridge of cartilage, which arches over the trigeminal nerve (5). The internal carotid artery (*i.c.*) finds its way into the pituitary space (*p.t.s.*) through a mass of soft fibrous stroma.

On the outer side of the primordial skull other parts can be seen; this view is given in fig. 5; here the facial arches are also shown. The nasal labyrinth developes with extraordinary rapidity, so that by the end of the first week all the main parts can be seen. Anteriorly the flat trabecular horn has expanded into the alinasal cartilage (*al.n.*), with its enclosed turbinal or vestibular flap (*n.t.*); behind this is the aliseptal region (*al.s.*), enclosing the inferior turbinal coil; and posteriorly there is the aliethmoidal lamina, which is continued downwards between the nose and the eye as the anteorbital plate or "pars plana" (*p.p.*)*. Fig. 6 shows a transversely vertical section (12 diam.) through the ethmoidal region, immediately in front of the anteorbital laminæ (*p.p.*), which are seen to be continuous with the aliethmoidal coil (*al.e.*), and to have no distinct "middle turbinal" outgrowth on their anterior face. In this view part of the cartilaginous sclerotic (*scl.*) is shown, and the section is also made through the middle of the palatine bar (*pa.*). Here is seen the true "schizognathous" condition of the palate; the mouth-cavity being continuous, between the narrow palatines, with the plicated nasal sac, although the chink between the rostral stroma (*r.st.*) and the anteorbital plate is very narrow.

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* The "pars plana" is continuous with the rest of the nasal labyrinth in all Birds; my earlier studies of these parts misled me; and in my paper "On the Osteology of the Gallinaceæ" (Zool. Trans., 1863, vol. v. p. 179) I spoke of this plate as being "autogenous in its cartilaginous state, as well as in its ossified condition." In the paper on the Ostrich's skull (p. 127 *et seq.*) this part was described as continuous with the rest of the nasal labyrinth.

Seen from the outside, the alisphenoid (*a.s.*) shows an oblique crest; this is the postfrontal plate (*p.f.*); it is largely developed in Fishes, but entirely absent (as is also the alisphenoid itself) in the Lizards and Chelonians. Infero-laterally the cartilage of the auditory region is scooped to form the tympanic cavity; but at present this part is filled with a gelatinous stroma, which grows very rapidly for a week or two and is then absorbed. The horizontal (*h.s.c.*) and posterior (*p.s.c.*) semicircular canals now shine out through the occipital cartilage, and the exoccipital region (*e.o.*) has developed its tympanic wing.

The quadrate cartilage (*q.*) has received a large and peculiar development, and, like the uncloven orbito-nasal septum, has attained a struthious condition. Anteriorly the little nodule figured in the First Stage (Plate LXXXI. figs. 1 & 2, *q.*) has grown into an arched blunt-pointed "orbital process;" inferiorly it has become a thick bar with two oblique condyles for articulation with the mandible; whilst posteriorly it has grown into a long arched crus, which not only articulates with the periotic capsule, above the junction of the prootic and opisthotic regions, but also with the exoccipital in front of the root of its tympanic wing. This articulation is shown in fig. 5ª (16 diam.) and fig. 5 (6 diam.), and it is seen to answer to what is depicted in my former paper on the Ostrich-tribe (Plates VII.–XIV.); in the Tinamou (Plate XV. fig. 1, *q.*) some recovery of the original position is attained *.

Where the quadrate cartilage articulates with the cranium, the side wall is somewhat scooped; but further down two small clefts appear, which, however, never go beyond the condition of fenestræ: these are the "fenestra ovalis" and "f. rotunda" (or f. vestibuli and f. cochleæ). The fenestra ovalis is, properly speaking, an aperture in the fundus of the cup-shaped articular cavity in which the head of the stapes (Plate LXXXI. figs. 5 & 5ª, *st.*) is articulated, and is morphologically like the acetabular fenestra of the Bird, and the glenoid fenestra of the *Proteus* and *Cryptobranchus* (see 'Shoulder-girdle and Sternum,' pl. 3, figs. 1 & 3, *gl.*).

From the first the parts of the hyoid arch are very inferior in size and later in development than those of the mandible; at this stage, after the quadrate has undergone so much modification and is so well chondrified, the stapes can only now be distinctly seen; and its outgrowths are mere bud-like projections from the main shaft. It is seen that the head of the quadrate projects some distance *behind* that of the stapes; but this truly ornithic modification is, exceptionally, only of short duration in the Fowl.

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* I must insist on the *zoological* importance of this condition of the quadrate, which is temporary in the Fowl and persistent in the Struthionidæ: in a large number of Birds the head of the quadrate, instead of being single as in the Struthionidæ and in this early stage of the Fowl, is divided into two short crura, one of which (the antero-external) keeps its normal place on the prootic, whilst the postero-internal crus retains the acquired (struthious) relation with the exoccipital ala. The Parrots come nearest to the Fowls in the forward position of both the articular facets, which are separated by a very narrow tract; in both these types the inner is slightly *behind* the outer.

At present the stapes is relatively a much more massive bar than afterwards; seen from the front and side (Plate LXXXI. figs. 9 & 10, 24 diam.) it appears as a flattened rod, curved forwards, with an oval head and a trilobate flattened base, the leading ray of which is most curved forwards and outwards*.

There is still a considerable tract of cartilage to be described in the proximal part of the face, namely the pterygo-palatine bar. The prenasal cartilage (already described) is an azygous prestomal counterpart of the Meckelian rods, although it does not become cloven from the primordial skull, and is never related to a free proximal cartilage, like the Meckelian bars; but the pterygo-palatine bar is perhaps the most difficult part of the cephalic skeleton to interpret. Seeing its primordial independence of the skull in the chick, and noting its early subdivision into a posterior short, and an anterior longer bar, it seems to be very feasible to compare its two divisions with the quadrate and the Meckelian rod. It lies above and *in front* of the great stomal cleft, much as the mandibular rods lie below and behind; but its point of suspension is a great difficulty; and the mind of the observer will revert to its various development in the Ichthyopsida. In the Chimæroids and in the Lepidosiren this part is not only continuous with the skull-base, but also with the prenasal cartilage in front, and with the common pier of the mandibular and hyoid arches (MÜLLER, 'Myxinoids,' pl. v. fig. 2; and HUXLEY, *op. cit.* p. 196, fig. 78, and p. 209, fig. 85); in the Frog the palatine passes, anteriorly, directly into the prefrontal cartilage (*op. cit.* p. 216, fig. 87). In the chick, the position of the pterygo-palatine bar is below and external to the basis cranii (figs. 5 & 6), from which it is separate from its first differentiation; it has, however, a much more intimate connexion with the quadrate, but is well differentiated from it on the fourth day (Plate LXXXI. fig. 1, *p.g.*, *q.*), and, indeed, has very different histological characters. The suspensorial parts of the pterygo-palatine bar are feebly developed, and are late in their appearance; these come to be below the optic foramen for the pterygoid, and below the prefrontal plate for the palatine: these will be described hereafter. At present the relation of the palatine bar to the prefrontal plate (fig. 6, *p.p.*, *pa.*) is totally unlike what is seen in the Frog; for, between the two, there is not only the thick fibrous stroma in which the delicate palatine bar is imbedded, but also the open channel which connects the cavity of the mouth with the interior of the nasal labyrinth. I would much rather interpret this bar by its specialized and freed condition in the Bird, than by what is seen in the low Vertebrate types, where the rampant growth of cartilage masks the proper morphological boundaries; and yet even in the high type the bar would seem to bear two interpretations—namely, that it may be a single arch, like the mandibular, the pterygoid being the equivalent of the quadrate; or, on the other hand, the pterygoid and the palatine may be merely the proximal parts of two arches, neither of which has a free descending ray; but I am extremely doubtful about the latter interpretation, and strongly incline to regard the mandibular, pterygo-palatine, and trabecular rays as true serial counterparts.

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* This bar must be studied at an earlier stage; in Cyclodont Lizards and Chamæleons the trilobate (hyoid) portion is quite distinct from the clubbed periotic rod.

The true histological growth and development of the pterygo-palatine bar has cost me much labour; only by examining sections made at many stages, and by seeing these under very high powers, has the meaning been made apparent. In a fresh-made section at this stage (Plate LXXXI. fig. 6) the tissues composing the ethmoid (*eth.*), the rostrum (*r.st.*), the palatine (*pa.*), and the sclerotic (*scl.*) do not appear very much unlike when seen by low powers; afterwards their differing characters may be seen. The cells composing the sclerotic (*scl.*) are smaller than those which make up the ethmoid (*eth.*); but they rapidly form hyaline cartilage; and both these tracts are more translucent than the rostral stroma or the cells composing the palatine. The latter can, however, be seen to transmit the light better than the rostral mass; and by the use of high powers (320 diam.) the structure of the rod becomes sharply distinguished from the nascent cellular tissue in which it is imbedded, and also from the more advanced connective-tissue cells of the rostrum. Much the greater part of the palatine bar (fig. 11) is composed of delicate, sharp-ended, fusiform cells of simple cartilage*, having large granular nuclei; but the pith of the bar is composed of still more delicate and smaller cells having an oval form, and without apparent nuclei—at least as seen magnified 320 diameters; it is this pith which is the first to ossify; and the transformation of the simple cartilage into bone is so rapid as to give the deposit the appearance of a membrane bone†.

The further development of the palatine bar will be described hereafter; and the pterygoid (*p.g.*), which is at present composed of simple cartilage similar to that of the palatine region, will be considered at the same time.

There now remain for description the free part of the facial (poststomal) arches; and the keystones that complete them. There is no keystone to the mandibular arch, which is entirely composed of the articulo-meckelian rod. This rod (Plate LXXXI. figs. 5 & 12, *m.k*, *ar.*) is a gently curved very solid bar of hyaline cartilage; it bulges and narrows two or three times, but does not greatly diminish in size even at its rounded anterior end.

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* Professor Huxley is disposed to look upon what I call "simple cartilage" as merely "indifferent tissue."

† For many years the development of the pterygo-palatine bar in the Sauropsida and Mammalia has been a great difficulty to me, as with moderately high powers, at stages more advanced than the one under notice, I could not well see how the main part of the bar differed from a membrane bone; yet I had discovered the existence of hyaline cartilage in several parts of the bar in Birds. In the Passerinæ and some others, the broad transpalatine angle is not ossified by the proper palatine centre, but by a separate endosteal deposit, and that long after the main bar, so that the simple cartilage gains time for a plentiful intercellular deposit. In the Woodpecker (*Picus viridis*) the inner edge of each palatine does not ossify from the main bony rod, but developes into hyaline cartilage, coalesces with its counterpart of the other side, and then slowly and feebly ossifies by endostosis, this centre being, properly speaking, an azygous "mesopterygoid." Hyaline cartilage may be found at the pterygoid end of the palatine proper in certain Birds (e. g. *Caprimulgus*); then it also appears in the counterpart facet in the pterygoid; it is always present on the quadrate end of the pterygoid; and whenever this bone articulates with a basipterygoid process, a meniscoid plate is developed on the corresponding part of the pterygoid. In many Reptiles (Lacertians and Chelonians) the posterior part of the subocular cartilage chondrifies and developes into a straight rod, which is obliquely situated above the fibrous or main pterygoid; ossifying separately, it becomes the so-called "columella:" the pterygoid of the higher Birds is more nearly related to this than to the underlying fibrous bone.

The articular portion is scooped in harmony with the swellings on the lower face of the quadrate; and from this part there project two finger-shaped processes; these are the internal (*i.a.p*) and posterior (*p.a.p.*) angular processes. Already these processes show the type to which the bird belongs; for they have a peculiar development in the whole "Gallo-Anserine" series, and in one or two *mixed* cognate forms (for instance, in the Flamingo); they attain their most extraordinary development in the "Tetraonine" sub-group of the Gallinæ, and especially in *Tetrao urogallus.*

In a somewhat earlier stage (head of embryo 4½ lines long, see Plate LXXXI. fig. 12, 12 diam.), notwithstanding the rapid elongation of the Meckelian bar (*m.k.*), these processes are scarcely more developed than in the Struthious Birds (see former paper, Plates VII.–XIV.), and the ends of these short processes are very knobbed. In this instance the nascent connective fibres surrounding these parts were quite free from osseous deposit, and so was the rest of the primordial skull, now representing the Cartilaginous Fishes; but in one a day or so older the splint-bones had commenced outside the perichondrium of the Meckelian rod (fig. 13, *su.*). Here the upper view of the articular part of the mandible shows that it is a bifurcating or partially double ray, which developes a groove-and-ridged articular surface on its upper face, at the point of bifurcation.

The next poststomal cephalic arch (the hyoid) is slow of growth, feeble in development, and rapidly gains an enclosed position, instead of maintaining its proper surface parallelism with the mandibles. The arches themselves (the cerato-hyals) are mere distal rudiments, such as we often see in the costal arches, a long space of mere fibrous tissue intervening between the arch and the pier. Their chondrification is *late*, as a correlate of their feeble growth. A somewhat earlier and stouter piece of cartilage appears between and behind them, the basi-hyal (*b.h.*); it is tear-shaped, with the pointed end foremost. Behind this, with its pointed end looking backwards, a longer and narrower piece appears; this is the so-called uro-hyal (*b.br.*), an azygous bar answering to the basi-branchial series of the Fish-class generally, and not to the "uro-hyal" of the Osseous Fish—which is a fibrous bone, a "basi-branchiostegal." The first branchial arch of the Fish is here represented by a stout ray segmented into an upper smaller (*e.br.*), and a lower larger segment (*c.br.*): these are they that suffer such extraordinary development in the Humming-birds and Woodpeckers, and which in typical birds always surmount the occipital plane, whilst in the typical Struthionidæ (*op. cit.* Plates VII.–XIV.) they are arrested at the stage here described in the chick.

Third Stage.—Head of Embryo from 8 to 9 lines long: middle of 2nd Week of Incubation.

Henceforth my work will fill both hands at once; for now the skeleton of the skin and its enfoldings will everywhere present itself side by side with the proper primordial parts of the skull-building; and, unlike what the easier problem of the lower types, as a rule, presents, we shall see the outer works growing upon and grafting themselves into the inner works, and afterwards both the skeletons becoming compacted together and growing into the simplest brain-casket in one part, and the most mobile prehensile organ in the other.

This third stage is in some respects parallel with what is seen in certain Teleostean Fishes, in which there is a free development of the cartilaginous endoskeleton, which is but little ossified, whilst the secondary or splint-skeleton is very frail and delicate; such skeletons are possessed by the Lump-fish (*Cyclopterus*), and by the Salmon.

In the illustrations of this stage the figures are drawn and magnified from embryos with the head two-thirds of an inch long; here several of the ectosteal patches have appeared within the perichondrium, and the splint-bones are all present. The primordial skull, when stripped of its infoldings and seen from below, presents the appearance shown in Plate LXXXII. fig. 1 (magnified 10 diam.); here the nasal labyrinth is not shown.

The prenasal cartilage (*p.n.*) has increased in size, and has become straightened so as to lie nearly on the same line as the septum nasi (*s.n.*) and ethmoid (*eth.*); it has not yet reached the acme of its growth, but has become spatulate at its end, and now well represents its large counterpart in the Plagiostomous Fishes, namely their azygous snout-cartilage. The base of the ethmo-vomerine plate (*s.n.*, *eth.*) gradually narrows to near the pituitary space (*p.t.s.*), where it rapidly enlarges, and has in its periphery first a pair of free plates (*a.p.*), and then a pair of continuous lobes or outgrowths (*l.g.*).

These free plates have, to me, only received an explanation after many years of work; on referring to my former paper (Plate VII. fig. 4, *a.p.*), it will be seen that in an embryo of *Struthio camelus*, the counterpart in development with this stage of the chick, the "anterior pterygoid processes" ("basipterygoids" of HUXLEY) grow directly out of the roots of the trabeculæ, in front and on each side of the pituitary space: the same thing takes place in the other Struthionidæ (*op. cit.* Plate IX.–XV.); and this state of things is also seen in the Lacertilia generally, and exceptionally in the Mammalia (for instance, *Cavia aperea**).

Collateral work has prepared me for seeing into the metamorphic modification of the skull-base of the Fowl as compared with that of the Ostrich. If the reader refer to the memoir on the "Shoulder-girdle and Sternum" (plates 16 & 17), he will see a precisely similar modification of parts that form the shoulder-arch; for, whilst the pre-coracoid of the Ostrich (plate 17. figs. 5 & 6, *p.cr.*) is continuous with the rest of

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* Here let it be remarked that my description of the base of the skull will differ considerably from that given in the Ostrich-paper. I have now found that the "rostrum" is not preformed in cartilage, that the pituitary floor is never filled in by cartilage, that the basitemporals are at first splint-bones and afterwards ectosteal plates, that, therefore, they do not perfectly correspond with the symmetrical basisphenoids of the Lizard, and, lastly, that, notwithstanding the different modes in which they receive ossific matter, the "basi-pterygoid" processes of the Lizard, the Ostrich, and the Cavy are all true representatives of each other.

the shoulder-plate, in the Pheasant (plate 16. fig. 4, *p.cr.*) it is a distinct segment, later and feebler in its chondrification than the main bar. All Birds above the Ostriches agree in this; whilst all the typical Struthionidæ have a Reptilian continuity in these parts: in this they agree also with certain low Mammalia, *e. g.* the Monotremata. The manner in which the simple clavicular membrane-bone grafts itself upon the detached precoracoid of the Fowl is precisely similar to the behaviour of the splints of the skull-base of the same and other birds. Like the precoracoidal segment, the basipterygoid plates (*a.p.*) are late in their appearance, as compared with the rest of the basisphenoidal region; their further development will be described hereafter. Ultimately it will be seen that there is nothing in the adult bird to distinguish them from those of the Ostrich, their smaller size and more forward position not being of any essential importance.

In the first stage (Plate LXXXI. fig. 2, *tr.*) the roots of the trabeculæ were seen to project outwards; in the next (fig. 8, *l.g.*) a retral lobe could just be distinguished on each side of the pituitary space; now a very perfect differentiation of this part is manifest, and a pair of very notable ear-shaped processes (Plate LXXXII. figs. 1 & 3, *l.g.*) are seen projecting backwards, one on each side of the deep "sella turcica." At present these parts are entirely cartilaginous, and present a peculiar appearance; for the cells in their interior are crowded together and full of granules (Plate LXXXI. fig. 16, magnified 250 diam.), so as to present the appearance of a very dark pith: this is similar to what is seen in the persistent trabecular rods of the Ophidia. The remarkable ornithic modification which these parts undergo will be described by and by; at present I make bold to assert that they answer to the unossified "lingulæ sphenoidales" of the human embryo: they receive their osseous deposit from another source, namely from the azygous parasphenoidal piece*; but to interpret the primordial skeleton by the after-deposits of bone is to study the *mask*, and not the *face*.

Behind the pituitary space the base of the skull, in its thick part, forms a very narrow waist; and the moieties of this pinched part are also contracted at their inner edge. This lateral retreat of the fore part of the "investing mass" gives rise to RATHKE's "posterior basicranial fontanelle" (*p.b.f.*); it is occupied along its mid line by the notochord (Plate LXXXII. figs. 1 & 3, *n.c.*): it is not, as I once supposed, the hinder part of the original hypophysial or pituitary space, cut off by the formation of the "posterior clinoid wall," but it is a subsequent modification, caused by the opening-up and widening of the primordial fissure in which the notochord lies; for the moieties of the investing mass are seen to press closely on the notochord in the first stage (Plate LXXXI. fig. 2); the chink is larger in the second stage (fig. 8); and by the end of the second week a wide lozenge-shaped space is formed (Plate LXXXIII. fig. 2, *p.b.f.*).

Gradually, as the skull outgrows the notochord, this region becomes the shelving postpituitary part of the basisphenoid.

The thin part on each side of the fontanelle is the root of the alisphenoid (*a.s.*)—

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* From a careful comparison of these parts in the lower Mammalia with those of Man, I feel satisfied that the bony "lingulæ" in that Class answer to the "basitemporal" rudiments of the "parasphenoid."

which is a crest of cartilage altogether continuous with the investing mass, and the root of the corresponding trabecula: this part will be better shown in the description of the fourth stage. On each side, and a little behind the posterior fontanelle, the investing mass rises into an elegant mammillary swelling; this is seen both above and below, and arises from the enclosed cochlea, the cavity of which, and the lower otoconial deposit, can be well seen when the skull is viewed by transmitted light (see Plate LXXXII. figs. 1 & 3, *c.l.*). These swellings reach to within a small distance of the notochord (*n.c.*); on the outside they are bounded, on the lower face of the skull, by the carotid groove (*c.g.*), and posteriorly they nearly reach to the foramen for the vagus nerve (8). The notochord (*n.c.*), which lies *above* as well as between the moieties of the investing mass, has *relatively* receded, through the more rapid growth of the surrounding structures; it is now at its fullest development, and osseous tissue has appeared on its upper surface, behind. Although belonging, in the early embryo, to the basioccipital region only, the notochord becomes constricted in several places (Plate LXXXII. fig. 3, *n.c.*) as if it were ready, if the investing mass were so disposed, to undergo hourglass-like segmentation.

The cells of which the swollen parts are composed are oval, thin-walled, and contain many granules (Plate LXXXII. fig. 5, 250 diam.); they form a good instance of cellular or indifferent tissue, as the intercellular substance is almost inappreciable. The osseous deposit takes place at first on the posterior third, on the upper face of the rod (fig. 3), and it appears as a fenestrate ectosteal plate (fig. 6, *n.c.*, 250 diam.): when once set up, the parent cells below soon disappear; and after a while the bony substance spreads over the investing mass (*i.v.*) on each side, and sets up endostosis in that part which, soon acquiring an inferior ectosteal place by the extension of ossification through the primordial chink, lays the foundation of the triple basioccipital bone.

Posteriorly another pair of smaller, but more convex mammillæ, are formed (Plate LXXXII. fig. 1, *o.c.*), these are the occipital condyles; between these, which have coalesced largely below, and in some degree above (fig. 3, *o.c.*, *n.c.*), a portion of the notochord projects, part of which belongs to the "atlas."

Outside the carotid groove the periotic portion of the investing mass becomes scooped into an oblong rounded sulcus. This sulcus has only a low wall in front, but is bounded behind by a large ear-like flap of the exoccipital lamina; this latter is the "tympanic wing of the exoccipital:" and the sulcus is the rudiment of the tympanic cavity (Plate LXXXII. fig. 1, *ty.*); at present it is filled with a soft flocculent stroma, soon to be absorbed.

The upper head of the quadrate is loosing its connexion with the occipital ala at the end of the sulcus, and is acquiring a cup-and-ball articulation with the fore part.

The low ridge bounding the sulcus externally is the rudiment of the "tegmen tympani" of the Mammal; the lower lip of the tympanic cavity is supplied by the fibrous skeleton, there being no such cartilaginous lamina as is seen in the highest Class.

At present the whole of the periotic capsule is unossified; but, besides the notochordal shaft, the occipital region has acquired a pair of triangular bony patches; these are the exoccipitals (Plate LXXXII. figs. 1 & 2, *e.o.*): they extend from the posterior selvedge to the vagus foramen; the bony matter is deposited on the inner face of the perichondrium, and soon sets up endostosis in the subjacent cells. Although commencing on the outside, the deposit soon spreads round the selvedge, along the inner face of the cartilage (Plate LXXXII. fig. 3, *e.o.*). The superoccipital lamina (Plate LXXXII. figs. 1 & 2, *s.o.*) is notched both above and below at the mid line; it is soft at present, but in a day or so acquires a small external bony patch on each side of the mid line: this is a mammalian character; and I know of only one genus (e. g. *Turdus*) in which the superoccipital is azygous. The symmetrical bony deposits seen in fig. 1 (*b.s.*) are *borrowed*, and will be described with the splint bones; the palatines (Plate LXXXII. figs. 1 & 7, *pa.*) are thoroughly ossified, and their subsequent increase is, in the Fowl, entirely at the expense of the fibrous investment, their primordial cartilaginous rod being the most transitory of any in the body; their ossification is by endostosis, the deposit commencing in the central pith of oval cells. As far as I know, this is the only instance of "primary endostosis" in the skull of the chick; in the old bird I shall describe a few endosteal patches in the nasal labyrinth *.

But the pterygoid, which is best studied at this stage, is ossified, like an ordinary shaft-bone, by "primary ectostosis" (Plate LXXXII. figs. 2 & 2B, *p.g.*), although but little of the cartilage ever becomes hyaline. The ectosteal deposit (fig. 10, *ect.*) soon spreads amongst and ossifies the cartilage-cells, which are large, extremely thin-walled, fusiform externally, and passing into almost polyhedral cells towards the interior: they contain a large granular nucleus. These simple cells are rapidly converted into bone, but much later than in the palatine bar. An ectosteal patch has appeared on the broadest part of the quadrate (fig. 2, *q.*), and an ectosteal ring on the lower branchial (Plate LXXXI. fig. 15, *c.br.*): these are all the bony deposits to be seen in the endoskeletal parts of the head at this stage.

The stapes (Plate LXXXI. fig. 14†, *st.*) has advanced very considerably in development, although entirely unossified; there can now be seen:—the wedge-shaped shaft (*st.*), the "extrastapedial" process (*e.st.*), which turns forward to apply its outer edge to the membrana tympani; the long antero-inferior process, the "infra-stapedial" (*i.st.*), which grows forward to apply itself to the lower lip of the tympanic cavity, and then becomes related to the basitemporal; and the crested postero-superior process, the "suprastapedial" (*s.st.*), to which is attached an ascending ligament. In fig. 14 the relation of the stapes to the fenestra vestibuli (*f.o.*) is shown; and in the section the squamosal (*sq.*) is seen outlying the periotic wall; then there is an open space above, which in the embryo is filled with an evanescent gelatinous tissue; mesiad of this is a section of the anterior semicircular canal (*a.sc.*): the vestibule (*v.b.*) is laid open; and the back wall of the cochlea shows by transmitted light the cavity itself, and the enclosed lower otoconial mass. Mesiad of the stapes the internal carotid (*i.c.*) is seen as it runs forward to gain the open pituitary space; and the section shows also how completely continuous the periotic cartilage is with the investing mass (*i.v.*). This section is viewed from *behind*; and being somewhat oblique, the left side shows the cochlea (*c.l.*) laid quite open, and the curled plate of calcareous granules (*ot.*) is seen lying in the inner end of the sac.

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* The additional ossifications which appear in the palatine bar in other birds commence, in the patches that are developed into hyaline cartilage, as endostosis—as the "transpalatines" of the Passerinæ, and the azygous "mesopterygoid" of *Picus viridis*. In the Fowl there is scarcely any primary endostosis in the body—merely in the carpals, tarsals, and epicnemial; for, as in the "Struthionidæ," their sternum is exceptionally ossified at first by ectosteal patches ('Shoulder-girdle and Sternum,' plates 16 & 17, pp. 182–191).

† The terms here used are taken from Professor Huxley's paper "On the Representatives of the Malleus and the Incus of the *Mammalia* in the other *Vertebrata*," Proc. Zool. Soc. 1869, pp. 391–407.

The delicate distal ceratohyals (Plate LXXXI. fig. 15, *c.h.*) have coalesced at both ends, a primordial chink being left along the mid line; the basihyal (*b.h.*), basibranchial (*b.br.*), and the branchials (*c.br.*, *e.br.*) have assumed much of their persistent form.

All the membrane bones have commenced, and several of them may be described at once; the relations of the remainder will be seen best in the next stage.

The premaxillaries (Plate LXXXII. figs. 2 & 2A, *p.x.*) appear in the thick, soft, fibrous investment of the prenasal cartilage (*p.n.*) *outside* the perichondrium; they are triangular at first, and then rapidly develope their nasal (fig. 2A), marginal, and palatine processes (fig. 2),

The maxillaries* (fig. 2, *m.x.*) are developed at some distance from the endoskeleton, in the fore part of that flap which grows downwards from the maxillary rudiment (see Huxley, Elem. Comp. Anat. p. 138, fig. 57 G, *l*); they are at first a delicate thread of fragile bone, pointed at each end, broad in the middle, and sending inwards, at their anterior third, a broad, recurved ear-shaped plate, which nearly touches the base of the septum nasi, and is the rudiment of the palatine plate or "maxillo-palatine." A much smaller style lies in the cheek-flap behind the maxillary; it is pointed at both ends, and its anterior end lies outside the end of the maxillary: this is the jugal (*j.*). Behind the jugal is the quadrato-jugal (*q.j.*); it is twice as large as the jugal, passes within it for some distance, becomes rather thick, and then curves inwards at its end to articulate with the quadrate. The nasals, frontals, parietals (not figured in the illustration of this stage) are delicate dendritic deposits in the soft fibrous tissues of the superethmoidal and cranial regions; the squamosal forms a bony eave to the prootic region (Plate LXXXI. fig. 14, *sq.*), and is formed, like the frontals and parietals, in the inner layer of the scalp, outside the perichondrium of the related cartilage.

With all these calcifying membranes every one is familiar; not so with those that substruct the base of the primordial skull.

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* In the former paper (Plates vii.–xv.) the maxillaries are everywhere described as "prevomers," a term strongly inveighed against since by Professor Huxley. At page 113 I spoke of these as the distinct counterparts of the palatine plate of the mammalian maxillary. I shall henceforth drop the term "prevomer," and call the Lacertian bone (the so-called turbinal) "septo-maxillary;" the bone described as the maxillary in my former paper (Plate xi. fig. 1, Plate xiii. figs. 12 & 13, *mx.* p. 141) may be called the "postmaxillary" (the Fowl does not possess it). I am now satisfied that although many birds have the additional Lacertian bone truly represented by maxillary outgrowths, yet these have no existence in the Gallinaceæ; and in no bird is there a distinct septo-maxillary: the counterpart of the exceptional "postmaxillary" of the Bird must be sought for far down amongst the Ganoid Fishes.

My description of these parts will differ considerably from that given in my former paper, as in my earlier observations I had mistaken the cellular tissue composing the "rostrum" for simple cartilage, and the two parosteal tracts behind it (the basitemporals) for ectosteal plates; the layer of cartilage, also, which I supposed ("Struthious Skull," p. 117) to form a floor to the pituitary space, has no existence in the Bird.

Professor HUXLEY (*op. cit.* p. 170) first showed that the so-called "basipresphenoid" of osseous Fishes is nothing but a membrane bone; in them, and in the Amphibia, a thick tract of *palato-faucial* subcutaneous fibrous tissue is converted into a large beam of bone, which runs forwards beneath the nasal region anteriorly, and backwards below the temporal region behind. This bone is well developed in the Amphibia (HUXLEY, *op. cit.* p. 214, fig. 86, B, *x*), and its posterior or temporal wings are outspread, whereas in the Fish they are often turned very sharply upwards. In the chick, in the next stage to be described, there is exactly such a tract of bone, but it has formed strong bony attachments to the true skull-base; at present this connexion has begun, but it is slight, and easily detached: but, besides this, the osseous matter is in three separate territories, instead of being one continuous sheet as in the Fish and Frog.

The anterior, narrow ossicle, the "rostrum," is styloid; it is formed by the conversion into bone of the rostral stroma figured in Plate LXXXI. figs. 6 & 7, *r.st.*; posteriorly osseous matter has run from it into the lower edge of the walls of the pituitary space; here the innermost part of a parosteal tract has become the ectosteal layer to the cartilage, and parostoses, ectostoses, and endostoses all run into each other, the first being the "cue" to the second and third: this I call the grafting of an *exoskeletal splint bone upon an endoskeletal region.*

The osseous deposit, so far forth as it has immediate relation to the cartilage of the pituitary region, forms a pair of basisphenoidal ossicles—the equivalents of the symmetrical basisphenoidals of the Lizard and of Man; these are figured as detached from the "rostrum" in Plate LXXXII. figs. 1 & 3, *b.s.*; on the upper surface (fig. 3) it is shown how the bony matter creeps round and into the trabecular root*.

The rest of the basis cranii is quite separable from the thick subcutaneous floor, and the breadth suddenly expands behind the pituitary region; so also the faucial portion of the fibrous mat is of great breadth (fig. 2, *b.t.*). In shape this layer is like the leaf of a *Bauhinia*, the "rostrum" answering to the leaf-stalk: the posterior margin of the bilobate mass is exaggerated, as to distinctness, in the figure; but in reality the web thins out rapidly in front of the exit of the vagus nerves (8): this sudden change in the thickness of the cranial floor is very remarkable, even in the adult bird.

Two large tracts of osseous deposit, the basitemporals, having a somewhat reniform outline, have already appeared in this thick fibrous web (fig. 2, *b.t.*); they are elegantly coral-like in appearance, and a row of feeble osselets lying along the grooved mid line are ready, *in a few hours*, to connect together the whole basitemporal tract. Not only do these symmetrical plates rapidly coalesce, but the "rostrum" also will have united with them by the time they have melted into each other; then the "parasphenoid" of the Ichthyopsidan will be fully represented, and the open pituitary space will be filled in below by the extraneous plate. It cannot be void of interest that the ornithic embryo is thus seen to arrive at its further goal by passing, at first, along Ichthyopsidan paths; not only is this seen in the skull-base, but also in all the outworks of the face.

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* In certain osseous Fishes (for example the Perch, Pike, Gurnard &c.) the prepituitary portion of the basisphenoidal cartilage is invested by a delicate ectosteal sheath; this azygous basisphenoid is thus confined to the front of the pituitary space through the remarkable development of the *prootic floor,* which takes up so much of the investing mass anteriorly.

The anterior termination of the "rostrum" is very thin; it lies in the midst of a large mass of stroma (Plate LXXXII. fig. 7, *r.b.s.*) underlying the perpendicular ethmoid (*eth.*), and above and between the laminar palatines (*pa.*): this section shows well how thorough the amalgamation of the trabeculæ becomes. *Conjugation* of symmetrical bands of simple cartilage at the mid line is a frequent phenomenon in the development of the skeleton.

Where the moieties of the "investing mass" embrace the pituitary body, and thus become *trabeculæ* (all the prenotochordal part of the early skull-base is trabecular), there the cartilage grows upwards into the alisphenoid (Plate LXXXII. fig. 4, *a.s.*), and downwards to form a steep wall to the pituitary space (*p.t.y.*): these walls are flanked by the "lingulæ" (*l.g.*); their nature, as outgrowths of the trabecular roots, and the dark appearance of their interior, is shown in this figure.

Fourth Stage.—Head of Embryo 10 *to* 12 *lines long: end of 2nd, and beginning of 3rd Week of Incubation.*

The primordial skull undergoes very rapid changes day by day; this will be seen at once if the figures in Plate LXXXII. are compared with those in Plate LXXXIII. All the figures in Plate LXXXIII. and figs. 8–12 in Plate LXXXII. are from a chick at the commencement of the third week of incubation, the head being an inch in length, or one-third larger than that from which the figures 1 to 7 in Plate LXXXII. are given; this stage, however, will be drawn nearer to the last by showing the structure of some younger embryos.

The basal view of the skull cannot be shown as merely primordial; so that fig. 1 in Plate LXXXIII. must be compared with figs. 1 & 2 in Plate LXXXII.: in this latter Plate the inner view of the skull-floor is only partially given, whilst in Plate LXXXIII. fig. 2 I am able to show the entire primordial skull from above, the grafted splints below not being focused.

But one of the most important changes to be noticed, and which was commencing but not described in the third stage, makes it profitable to compare the second with the fourth. We saw that in the second stage (Plate LXXXI. figs. 4 & 5) the cranio-facial axis had attained to a Struthious condition; in Plate LXXXIII. fig. 4 this part is seen to be rapidly passing into the Tinamine stage, the region common to the ethmoid and nasal septum having become largely fenestrate; this is intermediate between what is seen in

Tinamus robustus, where the "fenestra" becomes a "notch" (Struthious Skull, Plate xv. fig. 8, *c.f.c*), and *T. variegatus*, where it has not appeared, the skull in this respect being perfectly Struthious*.

The distinction between the perpendicular ethmoid and the septum nasi is merely histological in the Mammal; but here we see a true morphological cleft, which is now imperfect above and below, and never, in the Fowl, quite complete above, although this is common in the higher arboreal types.

The vertical orbito-nasal septum has undergone fission between the eyes, as well as between the olfactory sacs: a considerable series of these clefts appear in this plate in some birds, all after one fashion; but in the Fowl there are only two, and in the Struthionidæ only one. This posterior cleft divides the ethmoid (*eth.*) from the presphenoid (*p.s.*): this latter region is very feebly developed; for the fenestrate cleft ends below at a great distance from the base, and the ethmoidal and basisphenoidal regions meet below it.

The bar which encloses the anterior cleft below is very instructive; it is at present of considerable thickness (Plate LXXXIII. fig. 2, *s.v.l.*), although it is absorbed in a few days after this period. It is alate; and I propose to call the alar outgrowths the "supervomerine laminæ," to connect them with their persistent and more largely developed counterparts in the Frog and the Crocodile. They have their largest development behind (see Plate LXXXII. fig. 11, which shows them magnified 20 diam., and from below); the vomer commences below the middle bar at their front end (Plate LXXXIII. fig. 1, *v.*); when there are symmetrical vomers (as in *Picus*) they commence in the fibrous tissue below the laminæ. The posterior edge of the nasal septum is also alate (Plate LXXXII. fig. 4, *s.n.*), and has, in front of the alæ, an upper and a lower thickening, and a groove connecting these enlargements; this is caused by the burrowing of the nasal nerve as it passes downwards and forwards. In fig. 4 the aliethmoidal, aliseptal, and alinasal outgrowths are cut away (*al.e.*, *al.s.*, *al.n.*); the rounded and flattened prenasal cartilage (*p.n.*) is seen to have a somewhat downward direction.

The rostrum, or "anterior parasphenoid," is still quite distinct from the ethmoid, and a little also from the front of the basisphenoidal region; but directly beneath the optic nerves (2) it has grown into the substance of the cartilage, and the sella turcica is ossifying fast. The basitemporals (Plate LXXXIII. fig. 4, *b.t.*) are also rapidly coalescing with this common osseous mass, and they form a floor to the pituitary space (*pt.s.*) and also to the "posterior basicranial fontanelle" (*p.b.f.*). The notochordal shaft is now fast developing into the basioccipital bone, which still encloses the starving remains of the notochord; behind, in the unossified condyle (*o.c.*), it is still soft (figs. 1 & 4, *n.c.*).

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* This cranio-facial cleft (*c.f.c.*) is a perfectly ornithic character, and in *Tinamus robustus* is a beautiful correlate of the segmentation of the shoulder-girdle across the glenoid facet and the acuteness of the angle at which the scapula and coracoid are bent upon each other. On the 9th day of incubation the scapulo-coracoid bar of the chick is falcate and partly segmented; but by the time the cranio-facial cleft is well formed (14th to 16th day) the scapula has acquired a typical condition.

An upper view of the primordial skull at this period shows much that is noteworthy (see Plate LXXXIII. fig. 2, magnified 4 diam., and with the basal parts left out of focus). The nasal labyrinth is relatively very large, and posteriorly overhangs the orbital region; it is at once seen how large and important the structures are that are trabecular in their origin; their territory ranges from the pituitary space (*p.t.s.*) behind, to the end of the prenasal cartilage (*p.n.*) in front; the postpituitary or notochordal region is short, but very broad.

In this upper view of the skull-base the basioccipital (*b.o.*) is seen to have the form of a flint spear-head: it has a longitudinal ridge arising from the enclosed notochordal shaft; its point lies between the divisions of the occipital condyle (*o.c.*), and its blunt end lies between the cochlear elevations (*c.l.*). The cartilage does not extend far beyond the cochleæ, antero-mesially, but has retired far from the mid line; this state of things, combined with the rapid growth of the investing mass and the arrest of the notochord, has caused the "posterior basicranial fontanelle" (*p.b.f.*) to become a large lozenge-shaped space, merely filled with delicate stroma.

The exoccipitals (*e.o.*) are spreading; and the superoccipitals (*s.o.*) are large, and are approaching the mid line.

The prootics (*pro.*) are rapidly developing as ectosteal plates, in front of and below the ampulla of the anterior semicircular canal (*a.s.c.*); and a large ectosteal tract covers the middle part of the alisphenoidal region. The pituitary space (*p.t.s.*) is enclosed with derived bony matter; but a considerable amount of the anterior (*a.cl.*) and posterior (*p.cl.*) clinoid walls are still soft. All the rest of the skull (its trabecular portion) is still soft, and the notochordal regions are also, to a large extent, cartilaginous. The temporal wings of the exoccipital and the postfrontal outgrowths of the alisphenoid (*p.f.*, *a.s.*) are seen to be large masses of cartilage. The foramina ovalia (5) are very large fenestral spaces between the alisphenoidal and periotic regions; and the foramina rotunda (5 *a.*) are oval in shape, and pierce the root of the "greater wing." The centre of the alisphenoid is occupied by a fenestrate cleft (*a.s.f.*); this is cordate, with the apex downwards, and tends to divide the ala into two bars—an antero-mesial and a postero-external. The alisphenoids are wide apart mesially (exaggerated in the figure), and there is no more cartilage until we reach the mid line, occupied by the knife-shaped presphenoid (*p.s.*). Thus not only is the roof of the primordial skull occupied by an enormous fontanelle, but there are two mesial fontanelles in the lowest part of the floor, and its anterior or upper division is almost entirely membranous.

The division between the two basal fontanelles (the posterior clinoid wall) is imperfect above; in my former paper (Plate VII. fig. 1, & Plate IX. fig. 1, *p.cl.*) this is shown to be perfect in the Struthionidæ. In the embryo of *Struthio camelus* (Plate VII. fig. 1, *o.s.*) there is also a considerable tract of cartilage underlying the fore part of the hemispheres; this is formed of the lesser wings (orbito-sphenoids): these are aborted in the Fowl*.

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* The development of the sphenoidal region of the Fowl (and of *Carinate* birds generally) is thus seen to be clean contrary to what obtains in the Lacertilia, where the alisphenoids are absent, and the orbito-sphenoids are very large, fenestrate, and have (like the alisphenoid of the Bird) several osseous centres.

The broad roof-like frontal surface of the ethmoid (Plate LXXXIII. figs. 2, 4 & 5, *eth.*) ends in a long retral spur, which surmounts the olfactory grooves: there is no "crista galli." A deep chink on each side separates the aliethmoidal (*al.e.*) from the aliseptal (*al.s.*) regions, and a lesser chink marks the posterior boundary of the alinasal (*al.n.*) region. The diverging terminations of the alæ nasi retain their primary form as the out-turned trabecular horns; they closely embrace that azygous outgrowth of the trabeculæ which I have called the "prenasal cartilage" (*p.n.*); this snout-cartilage is now at its full size.

In the under view (Plate LXXXIII. fig. 1) I have depicted the splints that show themselves on the basal plane, whilst the lacrymals (*l.*) and frontals (*f.*) are merely indicated by a dotted outline.

The superoccipitals (Plate LXXXII. figs. 8 & 9, *s.o.*) have nearly met above the foramen magnum (*f.m.*); the exoccipitals (*e.o.*) have enclosed the vagus (8), and are enclosing the ninth nerve (9); behind they mount over the posterior semicircular canal (*p.s.c.*), and are spreading along the tympanic wings of the occipital cartilage.

The occipital condyle (Plate LXXXII. fig. 8, and Plate LXXXIII. fig. 1, *o.c.*) has a piece of the notochord (*n.c.*) projecting from its dimpled end; in front it ends below the basioccipital, which is under-floored, anteriorly, by the huge, expanding, almost coalesced basitemporals (*b.t.*).

On each side the lower edge of the squamosal (*sq.*) is seen dipping between the postfrontal and exoccipital outgrowths.

The rostrum (Plate LXXXIII. fig. 1, *r.b.s.*) is blunt-pointed anteriorly; it lies on a somewhat higher plane than the basitemporals, and has lost its former distinctness and simplicity, having ossified much of the lower part of the basisphenoidal cartilage (*b.s.*). But not only has this centre affected the overlying cartilage, it has grown into short wings between the heads of the pterygoids, forming the roots of the "anterior pterygoid processes" (*a.p.*), and into huge *pretemporal wings* (the "posterior pterygoid processes") (*p.r.p.*). The anterior pterygoid processes are capped with a cartilaginous plate (to be described anon), and the posterior wings have the "lingulæ sphenoidales" as their cartilaginous or endoskeletal root: this will be dilated upon when the sections are explained.

There is one more basicranial splint—the vomer (*v.*); this is a very small style, at present emarginate anteriorly, and blunt behind; but it changes its shape afterwards; it is developed in the same general tract of subcutaneous tissue as the "rostrum." The rest of the base of the cartilaginous axis is enveloped in soft fibrous stroma, which is only subject to ossification from lateral symmetrical points.

These symmetrical ossicles are developed in the subcutaneous stroma of the facial laminæ; they are the premaxillaries (*p.x.*), maxillaries (*m.x.*), jugals (*j.*), and quadrato-jugals (*q.j.*): all these have acquired considerable density since the last period. The palatines (*pa.*) are thoroughly ossified, and the pterygoids have lost most of their simple cartilaginous pith; a hyaline plate abuts against the anterior pterygoid processes, and the capped, unossified posterior end is acquiring considerable density.

The ectosteal sheath of the quadrate (*q.*) has spread largely; but the upper and lower condyles and the orbital process are still soft.

The occipito-otic region, when seen from within (Plate LXXXII. fig. 9), shows how the superoccipital bony plates spread over the posterior part of the anterior semicircular canals, and how the "prootic" ectosteal plate has begun to grow over the ampulla of the same canal.

Between the great anterior canal and the edge of the occipital plane, there is a large irregular fossa, filled now with gelatinous tissue, and afterwards with ingrowths from the parietal and squamosal. The alisphenoidal isthmus (*a.s.*), and the investing mass (*i.v.*), where it bounds the "posterior basicranial fontanelle," have been cut through. The left half of the same preparation, seen as an interno-lateral view, is shown in Plate LXXXII. fig. 10; here, besides a better view of the foramina, we see an additional proper periotic bony (ectosteal) plate—the opisthotic (*o.p.*); two more plates have yet to appear—namely, the "pterotic" and "epiotic" (mastoid).

The skull at this stage is still further illustrated by a posterior view (Plate LXXXII. fig. 8); and here the roof-bones are shown. The great upper fontanelle is being obliterated by the frontals (*f.*) and the parietals (*p.*); these are formed by an infinity of rapidly coalescing bony grains formed in the subcutaneous web: they are flanked by the squamosals (*sq.*), which have a similar nature. The two ascending occipital laminæ, although they have coalesced at the mid line, yet have left traces of their original distinctness in the upper and lower notch; the superoccipitals (*s.o.*) have not yet invaded this mesial part, nor have they reached the ascending edge of the fast-growing exoccipitals (*e.o*). Above the selvedge bounding the foramen magnum (*f.m.*) is seen the sinus canal (*s.c.*); and in the broad interspace between the super- and exoccipitals the horizontal (*h.sc.*) and posterior (*p.sc.*) semicircular canals shine out, and are seen to cross each other. Externally, and below the exoccipital region (*e.o.*), the elegant tympanic wings of the occipital cartilage form a thick crescentic selvedge. In Plate LXXXIII. fig. 4 the postorbital aspect of the skull is given; this is from a less mature specimen than that shown in figs. 1 & 2. Here, on each side above the optic nerves (2), and reaching to the olfactory crura (1), there is nothing but the laminar presphenoid, for a great extent, except membrane. This membrane is becoming bony by extension of the orbital plates of the frontals (*f.*); and infero-externally we have the alisphenoids (*a.s.*), which pass, to some extent, within the orbital plates. Much of the alisphenoidal lamina is still cartilaginous; but the *left* has an irregular ectosteal tract (*a.s.*1.) between the inner selvedge and the fenestra (*a.s f*). Another bony tract (*a.s.* 2) lies above the foramen ovale (5); on the right side these two plates have coalesced*. In my former paper (Plate VIII. fig. 1, p. 125) I showed that the alisphenoid (independent of its postfrontal outgrowth) had two bony centres in *Struthio* and some other birds: this appears to be the rule; but the postfrontal ossicle is not present in some of the higher (Passerine) types.

* This is a *reversed* figure.

The space between the "posterior pterygoid processes" (*p.r.p.*) and the basitemporals (*b.t.*) is filled with soft stroma, afterwards to be absorbed.

In Plate LXXXIII. fig. 5, a lateral view of the nasal labyrinth, orbital septum, and palatine is given, which shows how loose and membranous is the connexion between the ascending (orbital) plate of the palatine and the prefrontal or pars plana (*p.p*). The continuity of this anteorbital portion of the nasal labyrinth with the upper ethmoid (*eth.*), the aliseptal (*al.s.*), and with the alinasal (*al.n.*) is clearly shown: these parts will be better understood by reference to the sectional views; and by this means we shall also come to a fuller understanding of the rest of the skull at this stage.

I shall describe the sections from before backwards; and the first of these transversely vertical sections (Plate LXXXIII. fig. 6) passes through the middle of the prenasal rod: these sectional views are magnified from 8 to 16 diameters, and are given in Plates LXXXIII. & LXXXIV.

A section through the fore part of the beak (Plate LXXXIII. fig. 6) passes through the broadest part of the prenasal cartilage, which is seen to be more convex above than below: it lies in the midst of a mass of fibrous stroma which is being rapidly converted into the solid part of the premaxillaries (*p.x.*); these are thickest above, have a cultrate edge laterally, and have, already, a small marrow cavity.

A section made a little further back (fig. 7) shows the narrower cylindrical part of the prenasal rod, and passes through the tips of the trabecular horns, or fore part of the alæ nasi (*al.n.*). Here the premaxillaries (*p.x.*) are composed of three parts—the nasal process (*n.px.*) above, the dentary margin (*d.px.*) laterally, and the palatine process (*p.px.*) on each side of the prenasal rod; the section also shows the end of the maxillary (*m.x.*).

The next section (fig. 8) has caught the fore part of the septum nasi, and has passed through the alinasal fold (*al.n.*), the lateral nasal wall (*l.n.w.*), the nasal turbinal (*n.t.b*), the fore part of the maxillary (*m.x.*) and palatine (*pa.*), and the attenuated portions of the premaxillaries (*n.px, d.px, p.px.*).

Fig. 9 shows the formation of the inferior turbinals (*i.t.b.*); the section is made where the lateral nasal wall is deficient, so that the aliseptal plate turns abruptly upwards and inwards to form the inferior turbinal scroll, which has exactly two turns. The nasals (*n.*) and nasal processes of the premaxillaries surmount the labyrinth; and, leaving out other bony parts, I have shown the relation of the palatine plates of the maxillaries (maxillo-palatines, *p.mx.*) to the thick base of the the septum nasi.

The 10th figure illustrates the structure of the ethmoid behind the anteorbital plates; the ethmoidal roof (*al.e.*) is seen to be concave at the mid line, and convex laterally, the perpendicular plate (*p.e.*) to be thinnest at the middle, and the basal part to have the same bulbous outline as the septum nasi. Here, surrounded by a web of fibrous tissue, is seen the crescentic section of the "rostrum" (*r.b.s.*), and on each side the shelving section of the palatines (*pa.*) at their broadest part.

The next section (fig. 11) passes through the interorbital fenestra (*i.o.f.*). Above is seen that part of the presphenoid (*p.s.*) which runs into the perpendicular ethmoid anteriorly; it is only thickened above, and the orbito-sphenoidal regions (*o.s.*) are merely fibrous. The middle of the section is nothing but fibre—that of the fenestra; and below, the lower part of the presphenoid (*p.s.*) passes insensibly into the basisphenoid (*b.s.*). Here the "rostrum" (*r.b.s.*) is thicker, and the palatines (*pa.*) are cut through their thick but narrow pterygoid extremity. Only the lower part of the next two sections is given: in fig. 12 the soft fore end of the pterygoids (*p.g.*) is cut through, showing the enclosed cartilaginous pith; in fig. 13 the pterygoids (*p.g.*) are cut through where they interpose a cartilaginous plate between themselves and the "rostrum" (*r.b.s.*).

But the structure here indicated is better displayed in a section (fig. 14, 16 diameters) made through the basisphenoidal cartilage, exactly below the exit of the optic nerves, and immediately in front of the anterior clinoid wall. Here the section of the coalesced trabeculæ has a pyriform outline, the narrow end being upwards; this is enclosed in much fibrous tissue. Imbedded in this stroma is the rostrum (*r.b.s.*), which is here much broader, but less deep. Outside the upturned part of the rostrum there is, on each side, a plate of hyaline cartilage (*a.p.*), then a synovial cavity, then a similar plate of cartilage which is formed *in* the perichondrium of the pterygoid (*p.g.*) and *outside* its ectosteal tube.

This is very different from what obtains in the Lizard and in the Ostrich (First Paper, Plate VII. fig. 4, *a.p.*): in them the anterior pterygoid processes are direct outgrowths of the roots of the trabeculæ, and on their ends cartilage remains for articulation; in the Lizard this is very apt to acquire a rudimentary distinctness as a feebly ossified epiphysis; in both the Lizard and the Ostrich a cartilaginous plate appears on the corresponding part of the pterygoid.

Notwithstanding the different manner in which the basipterygoids of the Ostrich and the Lizard are ossified (namely, in the former from the extraneous "rostrum," and in the latter from the symmetrical basisphenoidal ectostoses), yet, morphologically, they correspond.

This dying-out of the cartilaginous shaft of the basipterygoid outgrowth in typical birds is very instructive, being an instance of morphological subdivision in a higher type of that which is continuous (uncleft) in a lower or more generalized form.

In the Fowl the "rostrum," insinuating itself between the basis cranii and the basipterygoid articular plate, becomes one with the true basis cranii, and, ossifying the inner face of the articular plate, leaves the rest soft for articulation with the pterygoid*.

The relation of the basitemporals to the basisphenoid is shown in section in Plate LXXXIII. fig. 4, which displays the postorbital region. In Plate LXXXIV. fig. 1, the lower portion of this section is shown, magnified 10 diameters.

This transversely vertical slice shows that the roots of the trabeculæ (*tr.*) are pyriform in outline (the broad part below) where they enclose the pituitary fontanelle. They are enclosed in a strong ectosteal sheath, the origin of which I showed, in Plate LXXXII. fig. 1, as being from the inner layer of the *parosteal* "rostrum;" the section is taken where the *grafting* first commenced. The bulbous base of these trabecular roots passes directly, behind, into the foremost part of the investing mass, where it encloses the posterior fontanelle (Plate LXXXII. fig. 1, *p.b.f.*), and also into the posterior clinoid wall (Plate LXXXII. fig. 3, *p.cl.*). This section well shows the absence of all cartilage under the pituitary body, and how the "sella turcica" is finished below by extraneous fibrous bone as in the Osseous Fish. The slice of cartilage seen on each side of the trabecular roots (front view) belongs proximally and below to the "lingulæ" (*l.g.*), and further outwards to the posterior clinoid wall, where it ascends into, and becomes the root of, the alisphenoidal lamina (see Plate LXXXIII. figs. 2 & 3, *al.s.*, *p.cl.*). There is no more cartilage below the thick-edged trabeculæ; the rest of the section is entirely formed at the expense of the thick cushion of stroma which intervenes between the primordial skull and the faucial skin.

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* I here use, indifferently, Professor HUXLEY's term "basipterygoids," and my older name, "anterior pterygoid processes."

The broadening end of the "rostrum" ("anterior parasphenoid"), after forming an ectosteal plate to the roots of the trabeculæ and to the "lingulæ" (Plate LXXXII. fig. 1, *b.s.*, *l.g.*), performs the same function for the anterior part of the posterior clinoid wall (Plate LXXXIV. fig. 1, *p.cl.*); and this it does until it reaches the lower alisphenoidal centre (Plate LXXXIII. fig. 3, *p.cl.*, *a.s.* 2). Wholly below the cartilage, however, the bony matter, which originally commenced in a fibrous tract, breaks away again from the primordial skull, and converts large tracts of fibrous tissue into bony wings. Outside the bony deposit, shown at fig. 1, *p.cl.*, the outstretching fibrous bands become bony; below the posterior clinoid wall, a strong double pillar of bone grows down from the mid line (fig. 1); and below, transverse aponeuroses are ossified, so as, with the upper wings, to enclose a large space, which becomes the "anterior tympanic recess" (*a.t.r.*). Between the lower wings there is a central tract of bone and two open spaces; and here, at every available point, the basitemporals (*b.t.*) are forming adhesions with the wings that grow out from the basisphenoid ("posterior pterygoid processes" of former paper, or, more accurately, "tympanic wings of basisphenoid"). Laterally the lower basisphenoidal outgrowths have not united with the basitemporals; thus there is a space (*eu.*) in which the eustachian tube is formed. Between the basitemporals there is another space; this becomes the back part of the common vestibule, in which the eustachian tubes meet at the mid line.

The histology of the thick cushion of stroma which intervenes between the primordial skull and the so-called mucous membrane of the fauces is peculiar. I have spoken of the aponeurotic bands in which the bony matter runs, and must now mention that the "anterior tympanic recess" (*a.t.r.*) and the eustachian passages (*eu.*) are, at present, full of a delicate gelatino-granular stroma, of a consistence little more dense than the mucous tissue of the umbilical cord of the Mammal; this soft sarcodal substance is soon absorbed to form the highly labyrinthic tympanic cavities.

Horizontal sections through the pituitary fontanelle throw light upon the perplexing morphology of this region of the skull*. The lowest of these (Plate LXXXIII. fig. 15) shows the internal carotids (*i.c.*) coming up from below; also the bony ring which surrounds the lower part of the pituitary body, the bony matter of which has spread right and left, ossifying a thick fibrous band (*f.*). Behind these "posterior pterygoid processes" is an open space, from which the gelatinous tissue has been removed, showing the formation of the anterior tympanic recess (*a.t.r.*); and behind this space the section passes through the lower part of the "posterior clinoid wall" (*p.cl.*), where it is growing up from the investing mass (*i.v.*). Between the moieties of this mass is seen the fore part of the "posterior basicranial fontanelle" (*p.b.f.*), which is being walled-in with bony matter. Higher up (fig. 16), above the "recess," the pituitary space is lined with a thin bony layer, which has grown up from below, whilst in front the bony substance (the same as seen at *p.cl.* in fig. 1) is just growing into the cloven "posterior clinoid wall." Behind this wall there is a thin layer of bony matter, which has crept up from the "posterior fontanelle" (fig. 15, *p.b.f.*).

Near the top (fig. 17) the thick cleft clinoid wall (*p.cl.*) is notched on each side, and the bony matter has risen up in front on each side of the notch.

Another transversely vertical section (Plate LXXXIV. fig. 2) shows, in a very instructive manner, the structure of the posterior sphenoid a little further back. The "posterior clinoid wall" (*p.cl.*) is seen to be connected by an isthmus above the fore part of the "posterior fontanelle" (*p.b.f.*); the bony matter of the "posterior pterygoid processes" (*p.r.p.*) touches the cartilage mesiad, and helps to roof-in the "anterior tympanic recess" (*a.t.r.*).

The moieties of the investing mass (*i.v.*) are here very steep, and they rest in depressions on the top of the thickest part of the massive basitemporals (*b.t.*). This section has been made behind the junction of the basisphenoidal outgrowths with the basitemporals, and well shows the membranous nature of the latter—the "posterior parasphenoids," the counterparts of the cross bars in the Fish and the Frog.

A section through the forwardly turned cochlear cavities (Plate LXXXIV. fig. 3, *c.l.*) shows the thickness of the periotic portion of the investing mass (*pr.c.*), and how the prootic ectosteal plate (*pro.*) is affecting this cartilage above, and the posterior pterygoid processes (*pr.p.*) are curling round it below. Below this latter plate is seen part of the "anterior tympanic recess" (*a.t.r.*), filled with gelatinous tissue. The floor is formed by the lower tympanic lip of the basitemporal (*b.t.*), which further inwards underlies the cochlear cavity (*c.l.*), and at the mid line makes a secondary floor to the large open chink in the cranial floor—the "posterior basicranial fontanelle" (*p.b.f.*). The cochlear otoconial deposit (*l.ot.*) is seen, folded upon itself, in the end of the cochlear sac.

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* I have spent a large amount of anxious labour upon the development of the sphenoidal region in the various types of the Vertebrate skull, and should be glad to work it out independently if time allowed. I will here suggest that the condition of these parts in the Fowl's skull be compared with what is seen in the Marsupial, Edentate, and Insectivorous Mammals.

Let it be noted here that the "anterior tympanic recess" is formed of fibrous bony wings which, in the Marsupial, grow directly from the alisphenoidal centre, and in the Insectivora (*Erinaceus*) from the basisphenoids. In Man the "lingulæ" evidently borrow their bony matter from the extraneous basitemporals; whilst in the Mammalia generally, although these splints are present, yet, as a rule, the lingulæ are ossified directly from the basisphenoid.

A section made a little further backwards (Plate LXXXIV. fig. 4) shows the sudden lessening of the thickness of the investing mass (*i.v.*) behind the cochlear elevation (*c.l.*). The last section (fig. 3) was made in front of the notochord; but here we come across its fore end (*n.o.*), which is enclosed in its own ectosteal sheath; this bony deposit is seen to grow upwards and outwards into the surrounding cartilage (*i.v.*), and is especially developing itself below, where it forms the lower plate of the basioccipital (*b.o.*). We are here close behind the basitemporal, in the broadest part of the basioccipital (see Plate LXXXIII. fig. 1, *b.o.*, *b.t.*). This section and the next to be described, well show the *triple* nature of the basioccipital, and also teach how small a portion of the morphology of the skeleton is involved in the mere consideration of the form and number of the separate bones.

The next section (Plate LXXXIV. fig. 5) is made where the skull-floor is thinnest—namely, just a little in front of the occipital condyle (see Plate LXXXIII. fig. 1, *b.o.*, *o.c.*). External to the basioccipital bony centre (*b.o.*) with the enclosed notochord (*n.c.*), the cartilaginous investing mass (*i.v.*) first becomes thicker and then thins out again; here it becomes enclosed within an upper and a lower ectosteal plate—the exoccipital (*e.o.*): this is more clearly shown in a more enlarged figure of this part of the section, given in Plate LXXXII. fig. 12.

The rest of the section passes through the otic region (Plate LXXXIV. fig. 5), and shows the inner wall, imperfect below (*pr.c.*), the vestibular or upper otoconial mass (*u.ot.*), the ampulla of the anterior semicircular canal (*a.sc.*), the ampulla and arch of the horizontal canal (*h.sc.*), part of the tympanic cavity (*ty.*), and part of the squamosal (*sq.*). This bone is separated from the periotic mass by a quantity of the same kind of gelatinous tissue as that which fills the tympanic cavity. The space between the squamosal and the periotic mass is very large, because of the deep angular fossa which runs along the outside of the anterior canal: this fossa is shown in Plate LXXXII. fig. 9, and in Plate LXXXIII. fig. 2, as well as in this section; it may be called the "upper periotic fossa."

Fifth Stage.—Head of Embryo 15 *lines long; 2nd Day after Hatching.*

The skull of the ripe chick (Plate LXXXIV. figs. 6–12) is interesting in many respects: it is profitable for comparison with the skull of the Fish, the Reptile, and the immature Mammal; and, looked at in its general form, it comes much closer to that of the nearest congeners of the typical Fowl than the skull of the adult bird.

The types suggested by a view of the chick's skull are the Hemipodiine, Pterocline, and Columbine outliers of the Gallinaceous Family (see Trans. Zool. Soc. vol. v. plates 34–38): the skull of the adult Fowl has receded greatly from that of its lower and more generalized relatives on one hand, and from its higher and more specialized congeners on the other.

The period of a week has sufficed for very great changes in chondrous and fibrous tracts; and now is the best nick of time for catching the true form of many of the osseous territories, although some have already lost their distinctness, whilst others have not yet appeared. The ectosteal tracts have set up "endostosis" in the cartilage lying between their plates, so that the true endoskeletal bones are being enlarged intrinsically as well as from the immediate fibrous layers. Save in the instance of the early grafted parasphenoids, the parosteal tracts (splint bones) are still altogether free from union with the endoskeleton, whether bony or cartilaginous.

The hyaline cartilage furnishing the interspaces and headlands of the ectosteal plates has become very dense through the abundance of the cheese-like intercellular substance; it is semitransparent when thick, and, for the most part, of a lilac colour.

The splint bones are still fibrous, but are beginning to become smooth through the fresh and fresh ossification of aponeurotic layers; as a correlate of this exogenous growth, the first deposit of bony matter is beginning to be absorbed in many directions, so as to form diploë: this is most advanced in the basitemporals and squamosals.

The drawings given of the ripe skull might, with very little modification, serve as diagrams to illustrate the structure of the skull in any bird above the Struthionidæ; with the "Præcoces" they answer as to *period*; but they correspond to nestlings of the "Altrices" at about the end of the first week after hatching.

The increased development of the occipital region is shown in Plate LXXXIV. figs. 6–10. The basioccipital (figs. 6 & 10, *b.o.*) has nearly obliterated the notochord, and the bony substance is spreading both laterally and backwards into the cartilaginous condyle; anteriorly (fig. 10) it has obliterated the spheno-occipital synchondrosis at the mid line. The form of the basioccipital is reptilian (lozenge-shaped) above (fig. 10), and mammalian (almost oblong) below (fig. 6).

The exoccipitals (*e.o.*) are growing into large wings, which reach up to the mastoid (epiotic) region externally and above, and approach the superoccipitals at the foramen magnum (fig. 9); inside (fig. 7) they are still quite distinct from the opisthotic (*op.*); and both outside (fig. 8) and inside (fig. 10) they have enclosed the anterior and posterior condyloid foramen (9) and the vagus-foramen (8). On the outer occipital plane (fig. 9), the exoccipitals trespass extensively upon the mastoid portion of the periotic cartilage (fig. 9, *h.sc.*, *p.sc.*); the true mastoid (epiotic) has not yet appeared.

The superoccipitals (fig. 4, *s.o.*) are fused together in their lower two-thirds, and form now a large shield of bone; internally (fig. 7) they enclose the whole crown of the huge anterior semicircular canal (*a.s.c.*) and the sinus canal (*s.c.*), which burrows along the outer face of the arch and escapes near the inferior angle (figs. 7 & 9).

The three periotic ectosteal plates which have at present made their appearance are all *inside* the cranial cavity (fig. 7). These are the front (prootic, *pro.*), the hinder (opisthotic, *op.*), and the small representative of the great otic wing of the osseous Fish (the pterotic, *pt.o.*); this latter bone can now be seen in the "lateral cerebellar fossa," on its front face*.

A deep fossa partly subdivides the periotic mass from the occipital ring on the inside (fig. 3, *op.*, *e.o.*); but the osseous centres are here not quite accurate landmarks of morphological regions, as the four periotic bones fail to wall-in the *upper*, *outer*, and *lower* portions of the auditory labyrinth: this is a reptilian state of things.

The prootic (*pro.*) is the earliest and, as a correlate of this, by far the most potent osseous growth of the four. The crested fore edge of the periotic mass helps, in front of and above the labyrinth, to enclose the cerebral mass; but the *lateness* of the small pterotic allows this cranial wing, both in the Bird and in the Mammal (see HUXLEY, *op. cit.* p. 245, fig. 97, *Pr.O.*, which shows this part in the skull of a Beaver), to be ossified by the early prootic; whereas in the Osseous Fishes the massive cranial wall is very greatly indebted to the pterotic, which is in them the largest of the periotic bones. The prootic of the Fowl (Plate LXXXIV. fig. 7, *pro.*), besides the scooped anterior crest, the front of which is notched for the trigeminal nerve (5), forms a large, backwardly turned, oblong plate, pierced along its middle for the compound seventh nerve. It is bifurcate above, where it creeps over the inside of the ampulla of the anterior canal, and also passes, in its posterior fork, to the other end of the arch; here it encloses the ovoidal pterotic plate (*p.t.o.*). The opisthotic (fig. 7, *op.*) is now a semielliptical wedge of bone, with its straight margin separated by a very narrow line of cartilage from the prootic, and its crescentic margin lying as a bank in front of the occipito-otic fossa; the line of separation between the opisthotic and the exoccipital (*e.o.*) is a very narrow band of cartilage.

The complex basisphenoidal region has now only one osseous centre, which, macerated away from the rest of the cranium, forms a most perplexing bone to one who has not followed its earlier history. Seen from below (Plate LXXXIV. fig. 6), we have its rostrum (*r.b.s.*), its great posterior wings (*pr.p.*), and its basitemporal floor (*b.t.*). Towards the end of the rostrum the low anterior pterygoid processes (*a.p.*) look downwards and forwards, and are covered with a meniscoid plate of cartilage. Behind them, at the mid line, the eustachian tubes open into one common vestibule, floored by the tips of the coalesced basitemporals. A notch, filled with tense membrane, is seen between the great upper wings and the basitemporals—these parts, in their meeting, not forming a perfect floor to the " anterior tympanic recess." The basitemporal plate is notched on each side, where it forms a floor to the tympanic cavity, and all along its posterior margin, where it partly underlies the basioccipital (*b.o.*).

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* This fourth periotic bone (the so-called "mastoid," in the Fish, of CUVIER and OWEN) was first determined by me, in a note to Professor HUXLEY, who spoke very cautiously about it at first (see his 'Elem. Comp. Anat.' p. 188). In my former paper I described this bone (which is very common in the Bird-class) as the epiotic (see Plates XI.–XIII., *ep.*); but it is too far forward for that bone; the true "epiotic" (see First Paper, Plate VIII. figs. 4 & 8, *op.*) is formed over the crown of the posterior semicircular canal. My error of taking the little pterotic for the epiotic misled me in naming the latter, which I supposed to be an *outer ectosteal plate* to the opisthotic element; and in the First Paper it will be seen that the letters *op.* indicate both a postero-internal (true opisthotic) and a supero-external (true mastoid or epiotic) patch of bone. I am indebted to Professor HUXLEY for leading me to see which was the true epiotic; then the pterotic unconsciously assumed its true name.

The side view (fig. 8) shows the high prepituitary part of the basisphenoid (*b.o.*) below the optic nerve (2), the rostrum (*r.b.s.*), and the tympanic lip of the basitemporal (*b.t.*).

The sectional view (fig. 7; the rostrum, *r.b.s.*, and anterior pterygoid process, *a.p.*, are not cut through) shows the rostrum, articular plate, prepituitary and postpituitary portions, the opening for the internal carotid (*i.c.*) in the fundus of the pituitary cup, and the thickness of the fast-growing basitemporals (*b.t*) where they underlie the equally thick shelving postpituitary part of the bone; the declivity is caused by the height of the posterior clinoid wall (*p.cl.*).

The end view (fig. 9) shows how the posterior margin of the basitemporals (*b.t.*) underlies the anterior end of the basioccipital (*b.o.*) and the surrounding cartilage.

The horizontal section (fig. 10) passes through the middle of the "sella turcica," cutting away much of the anterior and posterior walls, exposing the internal carotids, showing the basisphenoidal part of the cranial floor and the obliteration of the spheno-occipital synchondrosis at the mid line. Here the posterior or tympanic wings (*p.r.p.*) are seen to be thick and cellular, and to give attachment to the fore part of the membrana tympani (*m.t.*) in the long "anterior recess;" the prootic (*pro.*) helps to wall-in this recess behind.

The pedate tract of cartilage bounded by the basisphenoid, basioccipital, and prootic contains the cochlea, which is indebted to all these bones for its outer wall. The open fontanelle (*p.b.f.*) seen at the mid line in Plate LXXXIII. fig. 2, is here filled up by the rapidly growing basisphenoid; a chink, however, remains for a long time.

The windowed alisphenoids (Plate LXXXIV. fig. 8, *a.s.*) are now well ossified, all but the outstanding "postfrontal" (*p.f.*); the suture between the alisphenoid and basisphenoid remains long distinct.

On each side a large postorbital fontanelle still exists, reaching down to the optic nerves (figs. 7 & 8, 2) below, and upwards to the frontal plate of the ethmoid (*eth.*), traversing the whole of the orbito-sphenoidal region, which is devoid of cartilage. The orbital plate of the frontal (*f.*) is gradually encroaching on this unwalled space. The whole of the presphenoid (*p.s.*) and the hinder third and lower selvedge of the perpendicular ethmoid is still unossified; but a large antero-superior tract of the latter is now ossified by a double (right and left) ectosteal plate (figs. 7 & 8, *eth.*), the cartilage within undergoing endostosis.

The lower boundary of the cranio-facial cleft (fig. 7, *c.f.c.*) has been entirely absorbed, so that the ethmoid is now merely connected by an isthmus to the postero-superior angle of the septum nasi. Through this cleft (notch) the inferior turbinal coil (*i.t.b.*) can be seen; and below this cleft the vomer (*v.*) lies, in a perfectly ornithic condition, in the base of a plate of fibrous tissue, far away from the cranio-facial axis, and ready to lay hold on the fore spurs of the palatines (fig. 6, *v.*, *pa.*).

The nasal branch of the ophthalmic has left its burrow in the hinder part of the septum nasi, which has bridged it over both above and below.

The rather strong septum nasi (fig. 7, *s.n.*) ends in a rounded manner in front, and still retains, as a rostral process, the fast-diminishing prenasal or snout-cartilage (*p.n.*).

The swelling alinasal folds (*al.n.*), with their internal turbinal plate (*al.t.*), are best seen in fig. 8; and in it also can be seen the "pars plana" (*p.p.*), or lower part of the prefrontal plate.

The outer nasal wall (Plate LXXXIV. fig. 6, *o.n.w.*) and the prenasal bar (*p.n.*) are clearly seen from below, in the fore part of the palate.

The palatines (figs. 6 & 8, *pa.*), the pterygoids (*p.g.*), the quadrate (*q.*), and the stapes (*st.*) have all made a great approach to the adult condition. The pterygoids and palatines are well ossified; but the former have a cartilaginous cup for articulation with the quadrate, and a meniscoid plate (fig. 11, *p.g.*) for articulation with a similar disk on the anterior pterygoid process (*a.p.*, *r.b.s.*).

The meniscus which articulates the pterygoid to the basipterygoid facet is composed of typical hyaline cartilage (fig. 12, 200 diam.); this is separated from another tract of cartilage in immediate contact with the bone-cells; towards the fissure the cells are very much flattened; those in contact with the endosteal deposit are baggy simple cartilage-cells. Hence it is evident that this facet of the pterygoid is a proper segment of cartilage, and not a mere remnant of the main rod such as is seen on the quadrate end of the pterygoid.

The Fowl agrees with the Struthionidæ in having no mesopterygoid, contrary to what I once supposed (see Zool. Trans., vol. v. p. 157); in the Anatine series it exists as an exogenous spur to the pterygoid; in other Carinatæ it is segmented off.

The axis of the mandible (Plate LXXXIV. figs. 7 & 8, *art.*, *m.k.*) has acquired an ectosteal ring round its internal angular process ("manubrium mallei"); all the rest is soft, and the anterior end of this cartilage has begun to shrink (fig. 7, *m.k.*); this is an anticipation of what becomes of its counterpart ("processus gracilis mallei") in the Mammal.

The stapedial shaft-bone (*st.*) is shown in figs. 8 & 10.

The ectosteal sheaths of the "basihyal" and "branchials" have advanced considerably.

Part of the fibrous skeleton has been described in connexion with the basisphenoidal "stock" on which it is grafted; the rest of the splints are easily separable from the primordial cranium.

One pair only of these have coalesced at the mid line: these are the premaxillaries (fig. 6, *p.x.*); these have already become truly Gallinaceous, although in a generalized manner they have the "habit" of those of the adults of the lower types. In figs. 6 & 7 it is shown how these bones are causing, as it were, the absorption of the axis (*p.n.*) on which they were modelled*.

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* This is in conformity with what is so common in the building-up of the skull and face in the Warm-blooded Vertebrata—the "hoarding" and the "scaffolding" being formed subsequently to the proper walls and gates, which walls and gates have to be taken down to a great extent to let the hoarding and the scaffolding stand alone

The premaxillaries, anterior to their mesial coalescence, are normally ichthyic, with the exception that each bone developes a palatine process (fig. 6), as in the Mammal.

But the maxillary (figs. 6–8, *m.x.*) of the Fowl, above that of all other Birds, is ichthyic in a very remarkable manner; it is a perfect "os mystaceum;" and if the papillæ of the horny beak covering the premaxillaries may be considered (as in truth they are) to be potential teeth, then the maxillary is absolutely edentulous as in ordinary Teleostean Fishes: it is a very small, delicate style of bone, and, as in the Fish, has a double head, the anterior division articulating with the premaxillary, and the posterior with the palatine; as in the Fish, the posterior process is turned backwards.

The manner in which the Bird looks both ways (backwards to the Fish, and forwards to the Mammal) is well shown in the maxillary. In those low untypical Rodents, the Leporidæ, the dentary portion of the maxillary is abortively developed in front; and the second division of the palatine part of the Fowl's maxillary reappears in them as a narrow backwardly placed palatine plate. In most Mammals the palatine plate is truncated anteriorly to form the posterior boundary of the "anterior palatine foramen;" but in some, for instance the Pangolin (*Manis*) and the Hedgehog (*Erinaceus*), the palatine plate is sharply wedged-in anteriorly between the dentary and palatine processes of the premaxillaries, exactly as in the Fowl (Plate LXXXIV. fig. 6, *p.x.*, *m.x.*). The retral posterior palatine plates of the Fowl's maxillaries (maxillo-palatines of HUXLEY) are very thin, scarcely reach the vomer (*v.*), are fibrous, and are less developed than in any family except the Picinæ, where they only just appear mesiad of the inner edge of the palatine (see HUXLEY "On the Classification of Birds," Zool. Proc. 1867, pp. 448–450, figs. 30 & 31, *mxp*).

The rest of the maxillary of the Fowl is mere style (a zygomatic process), and ends free in the upper lip, having the jugal (*j.*) mounted on and overlapping it, exactly as in those Teleostean Fishes which possess a jugal.

The jugal (Plate LXXXIV. figs. 6 & 8, *j.*) is similar in form and size to the zygomatic process of the maxillary, and is less than the quadrato-jugal (*q.j.*), which finishes the fixing-bar to the quadrate (*q.*). The quadrato-jugal, like the rest of the facial splints, continues distinct from its surroundings. The nasals (fig. 8, *n.*) overlie the frontal part of the ethmoid imperfectly, as in Struthious Birds; they have a concave semielliptic margin anteriorly; this is bounded by an upper process, which outlies the nasal process of the premaxillary, and a descending facial wall-plate, which articulates with the premaxillary and maxillary below: this lower process is a typically ornithic structure, and is aborted in the Struthionidæ (see First Paper, Plates VII.–XVI., *n.*).

The lacrymal (figs. 6 & 8, *l.*) has a large superorbital and a thickish, twisted, anteorbital plate; these two parts are distinct bones in the Lizard.

The frontals (fig. 8, *f.*) are at present very elegant shell-like bones, rounded and smooth over the cranium, hollow and scooped over the eye, and having a strong superorbital ridge. The thin dentated orbital plate only partly walls-in the orbital fontanelle (*o.f.*). The oblong, curved, four-sided parietals (figs. 7 & 8, *p.*) are overlapped behind by the frontals (fig. 8); between the four bones, on the upper surface, is the well-known fontanelle (fig. 9, *fo.*). The posterior margin of the parietal has just reached the superoccipital (*s.o.*).

There is something very mammalian in the huge squamosals (Plate LXXXIV. figs. 6–9, *sq.*); they are, however, perfectly ornithic, having little of the Batrachian character such as is seen in the Struthionidæ; they are twice as large, relatively, as in Birds generally, and show a large square plate on the inside of the skull (fig. 7), thus supplementing the wall-plate of the prootic (*pro.*) and the alisphenoid (*a.s.*).

The squamosals of the Fowl do not show the bifurcate character so well as in the other families of Birds and of several mammalian types—for instance, *Cavia*, *Arvicola*, *Lepus*, &c. It is here (fig. 8, *sq.*) that the squamosal overlaps the whole side of the skull, over the piers of both the mandibular and the hyoid arches; thus, whilst it is the counterpart of the principal "supratemporal" of the Ganoid Fish, it extends over the region occupied by the "pterotic:" the posterior portion of the squamosal has a separate counterpart in the Lacertilia, just as in them the descending portion of the lacrymal is separately ossified.

In the mandible, however, the splint bones are as numerous in the Bird as in the Lizard; but the Fowl is exceptional in possessing no "coronoid" piece.

The dentary (Plate LXXXIV. figs. 7 & 8, *d.*) runs backwards almost to the articular facet; the splenial (fig. 7, *sp.*) is oblong, equidistant from the ends of the ramus, and hides half the Meckelian rod.

The surangular (figs. 7 & 8, *su.*) is more external than internal; the angular (*a.*) belongs equally to both faces, being laid on below; it flanks the long posterior angular process of the endoskeletal ray.

Sixth Stage.—Chickens about 3 Weeks old.

At first sight there appeared to be but little alteration, except general advancement of the ossification, in this stage; but the specimens examined were feebly grown, and had died in a somewhat atrophied condition. They yielded two new pairs of ossific centres—the postfrontals (*p.f.*) and the epiotics (*ep.*)—which I had never before succeeded in demonstrating in the Fowl; these are shown in Plate LXXXIV. figs. 13 & 14. I am rather inclined to suppose that these bony patches were more distinct on account of the arrested growth of the chickens; at any rate, they are very instructive, and the Fowl is thus seen to agree with the Osseous Fish and with many families of its own Class in the separate formation of these bones. In my former Paper (p. 129) I stated that the postfrontal of the Bird is an ichthyic bone, the so-called postfrontal of the Lizard being a postorbital subcutaneous scale. In this, as in many other respects, it is not the Lizard but the Teleostean Fish which is the proper forerunner of the Bird.

The epiotics (fig. 13, *ep.*) are small four-sided ectosteal plates, formed over the arch of the posterior canal, and having a somewhat indistinct and very transitory separateness from the exoccipital (*e.o.*).

Seventh Stage.—Chicken 2 Months old.

In this much more advanced condition of the skull many of the sutures still remain, the two new bones described in the last stage have already lost their distinctness, and two new pairs of osseous centres have appeared.

In Plate LXXXV. fig. 1, the left half of the skull is shown from the inside, and the orbital septum, not touched by the saw, is shown on its right side; this figure is magnified 3 diameters.

Altogether the structures have begun to acquire that massiveness which characterizes the skull of the Fowl equally with that of the Ostrich. The delicately toothed sutures above, between the roof-bones, and the narrow synchondrosial tracts in the primordial skull, make this a very fitting stage for comparison with the skull of a Reptile.

The notochord is now fairly vanished from the basioccipital (*b.o.*); but the vertical dimple in the condyle is a permanent remembrancer of what once existed; the bony mass which has swallowed it up and replaced it is now a massive lozenge, capped with cartilage behind. It is surmounted on each side by the exoccipital (*e.o.*), the smooth-faced wedge-like opisthotic (*op.*), and by the postero-inferior margin of the many-sided prootic (*pro.*). Crowning all these, there is the large elegantly sculptured superoccipital (*s.o.*), half of which is occupied by the arch of the great anterior canal (*a.s.c.*), which is margined by the sinus fossa and canal (*s.c.*). The prootic (*pro.*) is seen to be connected by its wall-piece to the four-cornered alisphenoid (*a.s.*), a narrow synchondrosis uniting them; the latter has not lost its fenestra (*a.s.f.*). The pterotic (*pt.o.*) is seen in the anterior aspect of the lateral cerebellar fossa.

There is now a basisphenoid (*b.s.*) as massive as the basioccipital, and containing, between its two clinoid walls (*a.cl.*, *p.cl.*), the elegant cup-shaped cavity for the "infundibulum," pierced below for the internal carotids (*i.c.*). In front of this cup the basisphenoid forms a thick low wall, above which the optic nerves diverge. Beneath the spheno-occipital synchondrosis the thick skull-base is made doubly thick by the massive basitemporal (*b.t.*). In front of this superaddition the basal part of the equally extraneous rostrum (*r.b.s.*) is capped on each side by the basipterygoid cartilaginous meniscus (*a.p.*).

The presphenoidal region (*p.s.*) is still soft, and the basisphenoid and perpendicular ethmoid are a long distance apart below; but along the thick upper edge of the presphenoidal cartilage there are now two pairs of bony plates—the fibrous representatives of the orbito-sphenoids.

The hinder pair evidently correspond to the ectosteal bars that appear behind the fenestra in the huge orbito-sphenoids of the Lizard; but as there are no cartilaginous "alæ minores," the ectosteal plate degenerates into a thickish "parostosis," and then grafts itself upon the indistinct orbito-sphenoidal lips of the presphenoid. The additional pair are very common in Birds; and I have mentioned the existence of two centres in the Emu in my former paper (p. 137), where they are described as part of the presphenoid; they do *cause* its ossification. The anterior bone (*o.s.*, 1) is irregularly oval; the larger posterior piece (*o.s.*, 2) is somewhat square in shape, and is fast wedged-in between the postero-superior margin of the presphenoid and the supero-anterior margin of the alisphenoid: these ossicles are still quite separable from the presphenoid, although afterwards they set up ossification in it*.

If the narrowest part of the tract of cartilage above the interorbital fenestra were quite asborbed, it would then be plainly seen what should be considered the true morphological boundaries of the perpendicular ethmoid (*p.e., eth.*). This does take place in some birds, as in the Cormorant, the Sun-bittern, and the Stilt-plover; and then the cleft also runs across to the common optic foramen, so that the small presphenoid is completely severed from the ethmo-basisphenoidal band below. In the Bird the presphenoid is to be regarded as a wedge with its sharp end below, cleaving the basal region where the basisphenoid and vertical ethmoid meet: this is a remarkable modification of the Vertebrate skull. The frontal and perpendicular regions of the ethmoid are not separately ossified as in the Struthionidæ (First Paper, p. 127 *et seq.*), but the ectosteal plates (right and left) work upwards through the frontal plate. At this stage the ethmoid is an irregularly oblong plate, finished in front but deficient above, below, and behind. The notched front margin is the posterior boundary of the great craniofacial cleft. In the figure the isthmus of cartilage is seen as cut through; below, there is a small hook of cartilage, the remnant of the lower boundary of the "fenestra" of the fourth stage; this piece partly lies in the grooved fore end of the rostrum. The position, relation, and advanced development of the three great splints (*f.*, *p.*, *sq.*) that wall-in the skull are shown in Plate LXXXV. fig. 1; anteriorly the frontal is seen to retire at the mid line, thus exposing the ethmoid above.

An outer side view of this stage of the skull is shown in Plate LXXXV. fig. 2, where the superoccipital is seen to be still quite separate, and the epiotic (*ep.*) nearly coalesced with the exoccipital. In the large sulcus behind the oblique cartilaginous selvedge of the prootic (*pro.*) is seen a wedge-like plate of bone (*pt.o.*), part of which appears on the outstanding edge of the exoccipital, in front of and below the remnant of the epiotic suture. This is the pterotic, the first ectosteal plate of which appears in the front and outer part of the "lateral cerebellar fossa" (fig. 1, *pt.o.*): its subsequent development is by endostosis; at this stage it has worked to the outer surface; and here it appears *behind* the prootic (*pro.*), in *front of* and *external to* the epiotic (*ep.*), and *above* the opisthotic (*op.*).

No one familiar with the skull of the Cod, Perch, or Halibut will fail to see how true the *geographical* relations of this little bony territory are to those of the great ichthyic "pterotic" *.

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* On this ground a parostosis and an ectostosis meet, and nothing but the history of the development of the parts could have given any clue to the matter; similarly, in the Mammalia, the "cornua sphenoidalia" or mesopterygoids crop up again as mere late ossifications of membranous tracts of the pterygo-palatine arcade; and, instructively as to the case of the Bird's double orbito-sphenoids, in Man the mesopterygoids are double on each side.

The coalescence of the epiotic with the exoccipital is a Reptilian character; but there is a tendency towards that affinity of the periotic centres for each other that we see in the Mammalia, inasmuch as the prootic, pterotic, and opisthotic unite together before they coalesce with the surrounding bones. Yet this is not very perfectly maintained; for the opisthotic begins to coalesce with the exoccipital about the same time that it loses its distinctness from the prootic (see Plate LXXXV. fig. 3, *op.*, *e.o.*).

The formation of the tympanic cavity in the Bird is extremely instructive; the space itself is the remnant of the primordial cleft between the first and second poststomal arches: this stage illustrates it well.

In Plate LXXXV. fig. 2 the occipito-otic mass is seen from the outside; in fig. 3 part of the same is shown, but the skull was tilted so as to give an infero-lateral view: it is magnified one half more than fig. 2. The floor of the ear-drum, instead of being formed primarily of the inferior periotic lip, and secondarily of the tympanic bone, as in the Mammal, is here altogether formed by the basitemporal splints. This massive bone (*b.t.*) underlies the eustachian tube (fig. 1, *eu.*), the "anterior tympanic recess," and the main part of the chamber. The great wings (*p.r.p.*) that grow widely from the "lingular" bud of cartilage form a roof and side wall to the "anterior recess;" the prootic (*pro.*) forms the roof of the main chamber, and the exoccipital (*e.o.*) by its large crescentic wing forms the posterior wall. Where the prootic and exoccipital meet above the opisthotic (*op.*), there is formed a very large air-cavity—"the upper tympanic recess" (*u.t.r.*); the two ear-drums communicate with each other through the diploë that lies between these upper recesses. The outer part of the opisthotic is seen on the inner side of the drum-cavity, as an oblique bar separating the fenestra ovalis from the fenestra rotunda. Above, the opisthotic *cochlear* bar has coalesced with the exoccipital (fig. 3); below and in front it is still separate from the prootic.

The outer notched edge of the prootic (from which the squamosal has been removed) is still soft at its selvedge, and a synchondrosial tract is seen running between this bone and the crescentic wing of the exoccipital. Halfway between the outer selvedge of the prootic and the fenestra ovalis there is seen a thickened rib of bone, which passes directly forwards, and is terminated by an oblique, subconcave, oval facet; this is the point of articulation of the inner head or prootic facet of the os quadratum (Plate LXXXV. fig. 8, *q.*, *pr.f.*); the other facet of the quadrate is much larger, and articulates with the squamosal (fig. 8, *sq.f.*). This facet for the quadrate lies a little behind the great outgrowths of the basisphenoid (*pr.p.*). This articular facet marks the great difference between the Fowl's skull and that of Birds generally; for this is the primordial point of attachment, which was once lost (Plate LXXXI. figs. 1, 2, 5 & 5^a, *q.*), and then regained, and has become persistent. This small cup on the outside of the prootic (a large distance from the front of the exoccipital) is very similar to that for the short crus of the "incus" in the fœtal Lamb. The Psittacinæ make some approach to the Fowl in the articulation of the os quadratum. It is in the Fowls—in the Common Fowl especially, and in the whole Gallo-anserine series to a great degree—that the basitemporals have their most massive development. This is correlative of the abortion of the "tympanics," which figure largely in many families of typical birds—the chief of the tympanic chain representing the "interopercular" of the Osseous Fish and the crown of the inverted arch of the tympanic ring of the Mammal. In the Fowl and in the true Gallinaceæ ("Alectoromorphæ," Huxley) I find scarcely a trace of ossification in the tendinous ring surrounding the "membrana tympani." In the Peafowl, however, a tympanic appears which is ornithically unique, although many birds have a chain of tympanics: this is formed in the posterior part of the shallow "meatus externus" (see Memoir on *Balæniceps*, p. 316), and therefore answers to the posterior part of the bony meatus of the Mammal; and lying as it does directly beneath the posterior process of the squamosal "supratemporal," it may represent the ichthyic "opercular" splint-bone*.

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* Professor Huxley would refer the epiphysis on the end of the outstanding occipito-periotic mass in the Lizard to this element, and he is undoubtedly right; the same centre keeps cropping up, in one form or another, in the Mammalia.

Eighth Stage.—Chickens 3 *Months old.*

The parts especially worthy of notice in this stage are the occipital, periotic, and posterior sphenoidal regions (Plate LXXXV. figs. 4–7; fig. 6 magnified 3 diameters, and the others twice the natural size).

The degree of coalescence of parts at this stage is illustrated by figures of the skull-basin. All but the parasphenoidal splints, which are so early engrafted upon the skull-base, are separable by maceration; only the symmetrical premaxillaries and dentaries have united at the mid line, the former very early, and the latter soon after hatching.

In the regions figured several of the smaller sutures are closed, and those that are still open are mostly narrow, so that the true shape of the bony territory is well shown. An upper and a lower notch still attest the original symmetry of the superoccipital (Plate LXXXV. figs. 5–7, *s.o.*). The exoccipital (*e.o.*) has completely absorbed the epiotic, which is now a mere region (*e.p.*).

The basioccipital (*b.o.*) is a thick, lozenge-shaped mass of bone, underlain by the basitemporal below (Plate LXXXV. fig. 4, *b.t.*, *b.o.*), and articulating above (fig. 5) with the basisphenoid, a notch in the mid line marking the end of the chink-like remnant of the "posterior basicranial fontanelle."

The more enlarged side view (fig. 6) should be compared with the like figure of the last stage (Plate LXXXV. fig. 2); and then it will be seen that the remnant of the epiotico-occipital suture is gone, and also the whole of that surrounding the outer part of the pterotic (*pt.o.*); its sutures have also disappeared from the inner face of the skull. The suture between the prootic and exoccipital (*pro.*, *e.o.*) is dying out at the middle, and on the inside only the upper part of the suture between the prootic and opisthotic remains; there is just a trace also, inside, of the suture between the exoccipital and the opisthotic. The whole para-basisphenoidal mass has long been one bone; the posterior wings (*p.r.p.*) strongly clamp the infero-anterior edge of the prootic (*pro.*), both above (fig. 5) and below (fig. 6). There are a pair of anterior clinoid spurs (fig. 5, *a.cl.*); behind these a pair of lateral spurs; and the posterior clinoid chink (fig. 5, *p.cl.*) is filled up with a mass of periosteal bone; behind this mass is the primordial chink, the remnant of the posterior fontanelle. The prepituitary part of the basisphenoid (figs. 5 & 6, *bs.*) has not nearly reached the perpendicular ethmoid; the latter part, with its surrounding cartilage, has been macerated away, leaving the rostrum (*r.b.s.*) as a long grooved style, having at its root the anterior pterygoid processes with their cartilaginous facets (*a.p.*).

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* I do not wish to push this doctrine of exact representatives, or "true homologues," too far; a perfect harmony of the whole splint-category in the Vertebrata generally will be obtained when our knowledge of this wide subject is perfect,—and not till then. I may, however, mention a curious modification of the "principal tympanic" of the Crows and Singing Birds, namely, that it enrings Nitzsch's "siphonium."

The alisphenoids were still connected with the basal mass by synchondrosis, so that these do not appear in the figures.

The head of the quadrate at this stage is shown in fig. 8; the squamosal facet is a hemisphere deficient at the inner side; there is then a ligamentous line, and below this, on the inside, a somewhat reniform subconvex facet for the subconcave facet on the fore end of the rod-shaped rib of the prootic (fig. 6, *pro.*, *q.c.*).

Ninth Stage.—Young Fowls of the 1st *Winter; from* 7 *to* 9 *Months old.*

The next stage may be considered to cover a period of two or three months, the specimens examined being such as were hatched in spring and killed at Christmas; here the approaches by which the adult condition is obtained are plainly shown.

A sectional view at the earlier part of this stage (Plate LXXXVI. fig. 14) displays the growing massiveness of the skull and the gradual closure of the sutures. Two extensive regions of the skull, namely the posterior sphenoid and the occipito-otic, now form one mass of bone (fig. 14, *s.o.*, *e.o.*, *b.o.*, *b.t.*, *b.s.*, *r.b.s.*, *pro.*, *op.*); but the larger (*a.s.*) and lesser (*o.s.*) wings of the sphenoid are still separate. The huge perpendicular ethmoid (fig. 15, *eth.*; fig. 14, *p.e.*) now, more than ever, displays its special ornithic development. I have failed to trace any upper osseous centre such as appears in the aberrant Struthionidæ; but the right and left ectosteal plates, continuous in front, set up endostosis in the enclosed wall of cartilage, and spread upwards, downwards, and backwards. Here the triangular osseous patch which appears on the upper surface of the skull, between the diverging frontals (fig. 15, *eth.*, *f.*), is not the same bone as that which shows itself in the same gap on the Ostrich's head (First Paper, Plate VIII. fig. 3, *eth.*): that is an upper ethmoid; in the Fowl it is merely a continuation of the perpendicular plate.

The bony substance spreads at the top laterally into the roots of the aliethmoids, forwards into the cranio-facial isthmus (between *eth.* and *s.n.* in fig. 14), and backwards into the retral process which overlies the olfactory grooves (1). Also below these grooves ossification is spreading into the ethmo-presphenoidal bar; in this specimen it has reached the foremost orbito-sphenoidal patch (*o.s.* 1); towards the base it is growing towards the fore part of the basisphenoid (*b.s.*). All the rest of the cranio-facial axis is still soft; and we now see the large size of the separating cleft, through which the upper and lower turbinals (*u.tb.* and *i.tb.*) are seen. The grooves for the nasal nerve (*n.n.*) almost cut off the gnawed postero-inferior angle of the septum nasi (*s.n.*); over the lower part of each groove there is a ridge of cartilage, from which in many birds there is an outgrowth partially occluding the nostrils, and strongly cemented to the lateral splints.

The prenasal cartilage (*p.n.*) still lingers in front of the rounded fore end of the septum; after this it rapidly disappears; indeed it seldom lasts so long, this specimen being exceptional.

The splint-bones are beginning to coalesce with the endoskeletal tracts; the parietals (*p*) and the squamosals (*sq.*) are partly fixed: the latter show a considerable surface on the inner side (Plate LXXXVI. fig. 14). All the rest of the splint-bones can be macerated away; their relations are shown from above in fig. 15, where the nasals (*n.*) are seen to have a considerable frontal portion.

The vomer (fig. 14, *v.*) is attached to the maxillo-palatine plate (*m.x.*), being widely dislocated from the base of the cranio-facial axis.

In the mandible the dentary (fig. 14, *d.*) and the splenial (*sp.*) are still separable from the fast-shrinking Meckelian rod (*m.k.*); but the angular (*a.*) and the surangular (*su.*) are partly anchylosed to the articular (*ar.*); this part, the counterpart of the bulk of the malleus, is now nearly ossified.

A more advanced skull is shown in Plate LXXXV. figs. 10 & 11, and Plate LXXXVII. fig. 1: here the free edge of the exoccipital wing (*e.o.*) and that of the postfrontal (*p.f.*) are still unossified; but the latter is now one with the alisphenoid, which is still separable from the basisphenoid (*a.s.*, *p.f.*, *b.s.*).

A narrow suture now separates the perpendicular ethmoid from the basisphenoid (Plate LXXXVII. fig. 1, *p.e.*, *b.s.*); they now meet below the still unossified part of the presphenoid (*p.s.*), which has, at last, appeared as a curved bony plate articulated by suture with the middle bar of the perpendicular ethmoid. Essentially a distinct bony patch, yet the presphenoid did not appear until the posterior orbito-sphenoid (*o.s.* 2) had affected its perichondrium; this process differs nothing from the grafting of the rostrum on the cartilage below. The alisphenoids are seen (Plate LXXXV. fig. 11) to be almost completely transverse in their position; but they overhang the postorbital space, being a continuation of the roof formed antero-superiorly by the orbital plates of the frontals (Plate LXXXVII. fig. 1, *f.*). The alisphenoidal fenestræ (Plate LXXXV. fig. 11, *a.s.f.*) are nearly filled-in by periosteal layers.

The squamosal is quite Batrachian in the Struthionidæ; it now suddenly foreshadows its counterpart in the highest Class.

I have already shown its large *inner* face (Plate LXXXVI. fig. 14, *sq.*); but its outer face is enormously expanded (compare Plate LXXXVII. fig. 1 with those in my former paper, Plates IX.–XIV.). The zygomatic process, in front of the articular facet, has not yet appeared; but above the facet the bone spreads equally forwards and backwards, in front overlapping the postfrontal and frontal, and behind covering the upper part of the mastoid and exoccipital regions; the hinder lobe overlies the root of the hyoid arch. When the coalescing roof-bones are removed by a saw, there is displayed what is seen in Plate LXXXVII. fig. 2: anteriorly the ethmoidal ossification (*eth.*) has advanced halfway to the isthmus, and backwards along the upper and middle bars; behind the latter is seen the small presphenoid (*p.s.*), having the hinder orbito-sphenoids (*o.s.* 2) on each side; in front of these is seen the smaller pair (*o.s.* 1). The alisphenoids (*a.s.*) are attached by a fibrous band to the posterior orbito-sphenoids; the large oblique groove for the 5th nerve (5) is seen to burrow them behind.

Behind the deep perforate "sella" is still seen the primordial fissure (*p.b.f.*) or fontanelle; and at some distance behind this is the ridge formed by the notochordal shaft-bone. The saw has passed through the periotic territory, so that the whole of the horizontal semicircular canal with its ampulla (*h.s.c.*) is seen—also its connexion behind with the ascending posterior canal, the ampulla of which (*p.s.c.*) and that of the great anterior canal (*a.s.c.*) are seen lying in the same plane; outside the ampulla of the horizontal canal the upper tympanic recess (*u.t.r.*) is exposed.

The under view of a similar skull with the lower part of the basitemporal removed, is shown in Plate LXXXV. fig. 9: here the common opening of the eustachian tubes (*eu.*) is laid bare, the posterior pterygoid processes (*p.r.p.*) are cut through, and the carotid canals (*i.c.*) and cochlea (*c.l.*) are exposed. The tympanic cavity (*ty.*) is seen growing forwards into the anterior recess (*a.t.r.*), and the opening into the upper recess (*u.t.r.*) is seen behind the double quadrate condyle (*q.c.*).

Another section, more highly magnified, is shown in Plate LXXXV. fig. 8; it is an upper view, and the saw has passed through a lower plane than in Plate LXXXVII. fig. 2. Here the stapes is seen *in situ*, and the membrana tympani (*m.t.*) is seen passing over its triradiate end to be attached, anteriorly, to the great posterior pterygoid process. Behind the vestibule (*v.b.*) is seen the base of the ampulla of the posterior canal (*p.s.c.*), and a section of the lower part of its arch. Mesiad of the ampulla is seen the opening for the vagus (8), and further inwards still that for the 9th (9). A bristle is figured as traversing the right drum-cavity and eustachian tube (*eu.*); and on each side of the eustachian opening the internal carotids (*i.c.*) come up. The part seen in shade, as the floor of the drum-cavity, is the basitemporal (*b.t.*).

The right stapes is shown in Plate LXXXVII. fig. 3 (6 diam.), from above, and at its base. The base is irregularly oval; the shaft, which with the base is ossified by ectostosis, is very slender; it widens, and then breaks out into a complex triradiate cartilage. The antero-inferior bar of this cartilage ("infrastapedial," *i.st.*) is slender and arcuate; the middle part ("extrastapedial," *e.st.*) is much broader and is spatulate; it curves forwards and downwards, and touches the postero-internal face of the quadrate. The postero-superior bar ("supra-stapedial," *s.st.*) is bifurcate at its free part, and from its lower edge there is a broad thin lamina which is continuous with the free end of the "extrastapedial," or middle process; a fenestra (*f.*) separates this oblique plate from the proximal part of the extrastapedial*.

This stage will be further illustrated by sections (principally transversely vertical, more highly magnified) (Plate LXXXVI.); these, for the most part, relate to the olfactory labyrinth, and complete what I partially described in the fourth stage (Plate LXXXIII.).

A view of the nasal labyrinth from within (fig. 10) and from above (fig. 11) will help to explain the larger sectional figures, which are magnified 4 times; the inner and upper views are one-half larger than the objects.

A section through the most swollen part of the alinasal folds (Plate LXXXVI. fig. 1) cuts through the thickest part of the nasal processes of the premaxillary (*n.*, *px.*) and through its sharp dentary edge (*d.px.*). The styloid end of the maxillary (*mx.*) and of the palatine (*pa.*) are seen below the palatine plate of the premaxillary (*p.px.*). Here the septum nasi (*s.n.*) is deep and thin, thicker towards the top, where it spreads into the arched alinasal folds (*al.n.*); these end free opposite the middle of the septum.

Halfway from their origin the alinasals give rise to the nasal turbinal (*n.t.b.*); the whole of this is seen in fig. 10, on its inner aspect. It first bends directly inwards, then passes downwards nearly parallel with the septum, and then curls outwards and upwards to its free edge.

But the nasal passage (*n.p.*) is rendered doubly valvular by a forward constriction of the cartilaginous nasal wall (*n.w.*), which (see fig. 11, *al.s.*, *n.w.*) is continued far forwards beyond the root of the inferior turbinal, or, properly speaking, beyond the aliseptal plate. The section of this wall of the nose is here elegantly S-shaped; it ends as a thick free edge near the roof, and as a thin free edge below; and there it is only separated from the base of the septum by the nasal nerve (*n.n.*).

A little further backwards (Plate LXXXVI. figs. 2 & 11) the section passes through the alinasal (*al.n.*) where it is dying out behind; here the nasal wall (*n.w.*) is cut through obliquely, and it is seen to end (below) much further from the septum. Here the nasal turbinal (*n.tb.*) is further from the mid line, and diverges outwards to a greater extent below; this section shows the thickest part of the dentary edge of the premaxillary (*d.px.*).

The next section (fig. 3) shows a front view of the inferior turbinals (*i.tb.*); these are also seen from the inside in fig. 10; they are coiled outgrowths of the aliseptal plate (*al.s.*), which is seen to divide halfway down, giving rise to the nasal wall (*n.w.*). This section happily passes through the very important bridge for the nasal nerve (*n.n.*), against which the aliseptal fold terminates as a free lamina, closely tied by fibrous tissue to the nerve-bridge. Besides the proper nasal floor, we have here a true bony palatine floor; for here the palatine plates of the maxillaries (*mx.*, *p.mx.*) are at their fullest development, and are expanded where they nearly meet each other and have the vomer (*v.*) wedged in between them below. A section through this part of the skull in the Turtle (*Chelone*), in the Pangolin (*Manis*), or in the Cat (*Felis*) would show precisely the same disposition of these parts, the vomer wedging itself in between the palatine plates of the maxillaries, which fail, where the vomer crops out, to meet each other at the mid line. At this part the upper and lower crura of the nasal (*n.*) are cut through; the dentary part of the premaxillary (*d.px.*) is becoming thin, the maxillary is at its greatest breadth, and the palatine is growing thicker. The feeble, ichthyic maxillaries (*m.x.*), instead of protecting the side of the face, are seen to be almost entirely at its base.

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* See also Professor HUXLEY's figures and descriptions, Proc. Zool. Soc. 1869, p. 398, figs. 5, A, B; and p. 406, fig. 8, C. These figures will be best understood by reference to what is seen in the Ouaran Lizard (*Psammosaurus*), where the bridge connecting the "extra-" and "suprastapedial" bars and the "fenestra" are absent: here the *tensor muscle*, which arises behind the "parotic bar," and above and behind the head of the quadrate, sends its tendon between the forks of the "suprastapedial"—which is bilobate as in the Fowl—to be inserted into the upper edge of the extrastapedial at its free end: the "infrastapedial" is shorter than in the Fowl. I here use these terms provisionally, as my researches into the structure of these parts in the Batrachia have satisfied me that these *prefixes* should have been set before the term "incudal."

The next section (fig. 4) is taken where the large chink is seen in the upper view (fig. 11, between *al.e.* and *al.n.*); here the aliseptal fold ends exactly where it has given off the inturned inferior turbinal coil (*i.tb.*); this coil has exactly two turns. Below, the posterior edge of the nasal wall (*n.w.*) is seen curving a little upwards where it touches the nasal nerve (*n.n.*). This section also passes through the maxillo-vomerine floor (*p.mx.*, *v.*); and here the nasal processes of the premaxillaries (*n.px.*) are flat, and the dentary processes (*d.px.*) are very small; the saw has passed through the nasals (*n.*) close in front of their bifurcation.

The next section (fig. 5) cuts through the nasals behind their bifurcation, and just takes off the fore end of the jugal (*j.*); two portions of the maxillary (*mx.*) appear in this section—namely, the zygomatic process, and the posterior edge of the palatine plate. As this section is taken behind the lateral chink, the nasal wall (*n.w.*) reappears below the inturned inferior turbinal outgrowth (*i.tb.*). The nasal nerves (*n.n.*) are seen turning downwards, and by their close contiguity they have aborted the septum nasi at this part; in many Birds, especially the Raptores, the postero-inferior angle of the septum is almost sawn off by these nerves. Another branch is seen to perforate the winged top of the septum, close below the nasal processes of the premaxillaries (*n.px.*).

In the next section (fig. 6) a front view is given of the end of the inferior turbinal (*i.tb.*), and of the anterior face of the upper turbinal (*u.tb.*); this section passes through the cranio-facial isthmus, which is still surmounted by the flat ends of the nasal processes of the premaxillaries (*n.px.*). On each side, the nasals (*n.*) form the roof-bones, which are flanked by the lacrymals (*l.*). The upper turbinal (*u.tb.*), like the lower, is seen to be an involution or outgrowth of the nasal wall (*n.w.*); and here at this point they lie one above the other; this is also shown in the lateral view in fig. 10.

In the next section (fig. 7) the inferior turbinal is cut away, and the interior of the upper turbinal (*u.tb.*) is exposed. Although appearing as a distinct outgrowth anteriorly (fig. 6, *u.tb.*), the upper turbinal is a mere bagged condition of the aliethmoidal lamina (*al.e.*) further back (see figs. 7 & 10).

A section through the fore part of the ethmoid (fig. 8, *eth.*, *p.e.*), showing the sharp front edge of the perpendicular plate, gives a front view of the back wall of the nasal labyrinth: in this figure the outer bones are not given.

This large back wall is the prefrontal plate, and much of it answers to the pars plana of anthropotomy. In this section the upper turbinal (*u.tb.*) is seen to be, at its posterior end, an outgrowth from the posterior wall of the nasal labyrinth; so that, although it is a mere swelling bag at its middle (figs. 7 & 10), yet it is a fixed outgrowth from the walls of the labyrinth at both ends. If the inner view of the left half of the cartilaginous labyrinth (fig. 10) be compared with the front view of its back wall, from which the turbinals have been cut away, leaving their roots, it will be seen that the inferior turbinal (*i.tb.*) is an outgrowth of the pars plana, posteriorly, and that its root there is continuous with that of the upper turbinal (*u.tb.*). Here there is no differentiation of a middle turbinal, except a small lamina (*m.tb.*) which grows upwards from the inner side of the root of the lower turbinal; in this respect the Gallinæ, like most other birds, are inferior to the Struthionidæ (First Paper, Plates VIII.–XIV. *m.t.b.*), which show a rudiment of those outgrowths which are so largely developed from the front face of the Mammalian "pars plana."

In this section the nasal nerves (fig. 8, *n.n.*) are seen entering the labyrinth close below the roots of the cartilaginous aliethmoid (*al.e.*); whilst the smaller olfactory crura (1) enter between the widening part of the perpendicular ethmoid (*p.e.*) and the convex margin of the crescentic root of the upper turbinal (*u.tb.*), close above a little horn-like process growing from the supero-internal angle of the pars plana (*p.p.*).

The rostrum of the basisphenoid (*r.b.s.*) reaches so far forwards as to underlie the cultrate fore edge of the perpendicular ethmoid.

A section (fig. 9) made through the most solid part of the ethmoid displays much that is instructive. The nasal processes of the premaxillaries (*n.px.*) are reduced to delicate flat styles; the nasals (*n.*) are still of considerable breadth, and overlie the wedge-like fore ends of the frontals (*f.*). The lacrymals (*l.*) send out here their broad superorbital plate, and grow downwards into an imperforate styloid anteorbital process; on the inside of each lacrymal, in the recess between this bone and the nasal labyrinth, is seen the pyriform nasal gland (*n.g.*). The huge perpendicular ethmoid (*p.e.*) has here grown out largely into the aliethmoidal wings (*al.e.*), only leaving the very edge soft, from which a narrow isthmus grows downwards, outside the nasal nerve, connecting the broad top of the ethmoid with the supero-external angle of the anteorbital (prefrontal) plate. This flat, smooth, subconvex sheet of cartilage, the anteorbital, is oblong in general form, and has sinuous edges, the inner of which, although quite distinct from, yet lies close to the perpendicular plate. In the Fowl, even to old age, it is soft; but in many birds it is ossified, and is extremely apt to form bony adhesion with the perpendicular plate. Below the anteorbitals the median plate becomes suddenly thin, swelling a little below, where it lies in the grooved rostrum (*r.b.s.*).

In this section the thick outer and the sharp orbital parts of the palatines are seen;

the latter processes lie near the rostrum, and are enveloped in the same stroma; this projecting part forms an imperfect septum between the middle nasal passages (*m.n.*), which open into each other below (compare this figure with Plate LXXXIII. fig. 10, *p.e.*, *p.a.*, *r.st.*).

The whole nasal labyrinth is continuous; the prefrontal wall, the outer wall, the turbinals, and the alæ nasi are all developed from that tract of the primordial skull which curls downwards, in front of the pituitary space, into the frontal wall of the embryonic skull (Plate LXXXI. figs. 1 & 2).

This free growth of cartilage into so many morphological territories is correlative to the simplicity of the tissue, which rises but a step or two beyond protoplasm, is ready to be metamorphosed into any other skeletal tissue, and yet serves as a persistent skeleton to many parts, especially those of the nasal labyrinth.

The quadrate end of the pterygoid is lined with flat-celled hyaline cartilage (Plate LXXXVI. fig. 12, *c.*), and the contiguous osseous tissue (*o.*) is formd by endosteal metamorphosis of more swollen cells.

When the cartilage-cells of the articular facet are viewed endwise (fig. 13, *c.*), they are seen to have an oval outline. The meniscoid facet has not changed, except in size, since the time of hatching.

Tenth Stage.—Fowls several years old.

By the time the young Fowl is a year old most of the cranial sutures are completely closed; and then, year by year, the skull becomes more and more dense, the periosteal layers filling-in every vacant space not needed for the transmission of vessels and nerves.

Thus in the skull of an aged bird (Plate LXXXVII. figs. 4–10) the occipital, otic, posterior and anterior sphenoidal, and the ethmoidal regions have become one continuous bone, with the old landmarks all removed, and scarcely a sign left of its once highly complex condition.

This state of things, for a bird, is quite normal; and although carried to a very high degree in the Fowl, yet in some more typical birds the obliteration of all signs of the once composite condition of the skull is still more perfect.

The present paper is linked on to the first by the description of the skull in the aberrant Struthionidæ (Tinaminæ, or Dromæognathæ); in those birds there is some falling away from what is typically struthious, and some approach to what we have here in the higher Gallinæ. In the skull, however, the Tinamous, wherein they diverge from the Ostrich-tribe, do not equally approach the Gallinæ, but rather show affinity to the Charadriomorphous types.

This, however, is not all; for the Tinamous have a tincture of the Reptilian nature in them; and whilst the sutures close very perfectly in the Ostrich, as in the Fowl and other typical birds, in them several of the most important of those landmarks remain throughout life (see First Paper, pp. 174–178, Plate xv.).

In the side view* of the skull of an old male (Plate LXXXVII. fig. 1) we see how largely the face has gained upon the skull as compared with what had obtained in the ripe chick (Plate LXXXIV. figs. 6–9), where the face had the feebleness seen in the Sand-grouse (*Syrrhaptes*).

A zygomatic process has grown downwards from the squamosal (Plate LXXXVII. fig. 4, *sq.*), and this has formed a bridge over the lower part of the temporal fossa by coalescence with the postfrontal (*p.f.*). The fenestræ in the posterior orbital wall are all filled up, and the olfactory opening (1) is merely large enough for the nerve, whereas it once lay in a sheet of membrane.

In Plate LXXXVII. fig. 4 a trace of the interorbital space (*i.o.s.*) still exists; but in another specimen (fig. 8) the periosteal layers of bone have completely obliterated it; in the same figure which shows the inside of the cranial cavity and the left side of the orbital septum, it is seen that the rostrum (*r.b.s.*) has completely coalesced with the base of the perpendicular ethmoid (*p.e.*), and that the upper part of the ethmoid (*eth.*) has stopped its ossification at the cranio-facial isthmus. The nasal labyrinth, which is not displayed in these figures, is but little altered since the first winter (Plate LXXXVI.); but four small endosteal patches have appeared (Plate LXXXVII. fig. 10) in front of the ethmoid (*eth.*). One of these is in the isthmus; another, close in front of it, is formed in the postero-superior margin of the septum nasi (*s.n.*); and on each side of these there is one formed in that thick bridge of cartilage which protects the upper branch of the nasal nerve (Plate LXXXVI. fig. 14, *n.n.*). In the late, arrested condition of the nasal ossicles, the Fowl differs much from a large number of Birds, especially the aërial Desmognathæ; and many also of the Schizognathæ are less Reptilian in this respect than the Fowl†. The nasal bones (figs. 4 & 6, *n.*) have coalesced posteriorly with the frontals (*f.*); but the latter are wedge-like, and divergent in front, and thus expose the upper surface of the ethmoid (*eth.*): this is a Struthious character; originally, however, it answers to the skull of the Osseous Fish; it is occasionally seen in the Lizards, for instance the Iguana. The nasal processes of the premaxillaries (*n.px.*) have neither coalesced with each other, nor with the surrounding parts; the maxillæ (*mx.*), the jugals (*j.*), the quadrato-jugals (*q.j.*), and the lacrymals (*l.*) keep their distinctness to old age.

On the lower surface (Plate LXXXVII. fig. 5) the palatines (*pa.*) maintain their separateness from the palatine plates of the premaxillaries (*p.*), and also from those of the maxillaries (*mx.*). The small vomer (*v.*) also is merely attached to its surroundings by bands of fibrous tissue. The pterygoids (*p.g.*) are attached to the palatines by a rough sort of hinge, and to the quadrate (behind) by a shallow cup, which receives the pterygoid facet of the quadrate. This latter bone (*q.*) acquires a strong trochanter in front of its upper head; below it is deeply notched, where it projects backwards from the mandibular facets, for the quadrato-jugal, which is curved to wind round the base of the quadrate (see Plate LXXXVII. figs. 4 & 5, *q.j.*, *q.*).

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* These figures of the skull of old Fowls are from preparations made in the usual way, namely, by destruction of the soft parts; so that the nasal labyrinth and septum are not shown: these figures are good for comparison with those given of adults of related types in my paper on the Gallinæ (Zool. Trans. vol. v. pls. 34–40).

† These terms are taken from Professor Huxley's paper "On the Classification of Birds," Proc. Zool. Soc. 1867, pp. 415–472.

The mandibles vary considerably in individuals: in the one figured (fig. 4) there is scarcely a trace of the great fenestra seen in the Tetraonidæ (Zool. Trans. vol. v. pl. 36, fig. 9); but in others it is present. There is generally some trace of the suture between the posterior wedge of the dentary and the angular and surangular; but all the other sutures close; the dentaries anchylose with each other early, like the premaxillaries. In the hyoid arch the stapes undergoes no further change; the lesser cornua of the hyoid (Plate LXXXVII. fig. 11, *c.h.*) coalesce to form a glosso-hyal; but the tip of the coalesced cartilage continues soft, and a fontanelle is persistent between the bony part; this elegant sagittiform tongue-piece articulates with the basihyal (*b.h.*) by a synovial hinge.

The basihyal is carinate above, and behind articulates by a small synovial joint with the long, slender, proximally ossified basibranchial (*b.br.*). The branchial arch articulates below by a gliding synovial joint to the end of the basihyal; but the proximal piece, or "cerato-branchial" (*c.br.*), is articulated to the distal, or "epibranchial" (*e.br.*), by a mass of connective fibre; the proximal (lower) piece is soft above, and the upper piece at both ends.

When the outer table of the dense aged skull is removed, the semicircular canals (Plate LXXXVII. fig. 9, *a.s.c.*, *h.s.c.*, *p.s.c.*) are seen to be imbedded in a moderately delicate diploë: in the figure the outer tympanic walls are removed, and show the fenestra ovalis and fenestra rotunda (*f.o.*, *f.r.*) on the surface; a bristle is shown as passing along the tortuous canal for the internal carotid artery.

The figures, as compared with what is seen in Aërial Birds, show what every one is familiar with in the natural skull, namely the *non-typical* coarseness and strength of the whole skull and face*.

Concluding Remarks.

Having thus, with as much expedition and brevity as I have been competent to, run through the ten arbitrary but not unnatural stages in the morphological history of the Fowl's head, I would conclude by hinting at the importance of the various isomorphisms displayed by the skull and face of this one type in its stages of growth.

I have described it *upwards*, but my long and really anxious labour has been in the opposite direction; the stages were traced from that of the old bird *downwards* to that of the chick of the 4th day of incubation.

Whilst at work I seemed to myself to have been endeavouring to decipher a *palimpsest*, and one not erased and written upon again just once, but five or six times over.

Having erased, as it were, the characters of the culminating type—those of the gaudy Indian bird—I seemed to be amongst the sombre Grouse; and then, towards incubation, the characters of the Sand-grouse and Hemipod stood out before me. Rubbing these away, in my *downward* work the form of the Tinamou looked me in the face; then the aberrant Ostrich seemed to be described in large archaic characters; a little while, and these faded into what could just be read off as pertaining to the Sea-turtle*; whilst, underlying the whole, the Fish in its simplest Myxinoid form could be traced in morphological hieroglyphics.

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* In a Jungle-fowl (*Gallus bankiva*) which I dissected for Professor Huxley, the skull was much more fibrous and less dense than in the tame Fowl: it was more like that of the Pheasant.

I have but little used the suggestions of comparison, which have almost been burdensome at times; but other monographs must follow; and that of the Osseous Fish, which I hope to offer next, will show how gentle and gradual are the metamorphic changes by which the skull and face of a Vertebrate animal grow into harmony with the most diverse conditions and habits of life.

Description of the Plates†.

PLATE LXXXI.

First Stage.—Head of Embryo, from beak to occiput, 3 lines long: 4th Day of Incubation.

Fig. 1. Under view of head. × 9 diameters.

Fig. 2. Upper view of basis cranii. × 9 diameters.

Second Stage.—Head 4 to $5\frac{1}{2}$ lines long: 5th to 7th Days of Incubation.

Fig. 3. Vertical section of skull and face of an embryo with head 4 lines in length. × 6 diameters.

Fig. 4. Ditto, with brain removed, of an embryo with head 5 lines long. × 6 diameters.

Fig. 5. Side view of same. × 6 diameters.

Fig. 5A. Part of the last (auditory region). × 16 diameters.

Fig. 6. Section of the same through nose and palate. × 12 diameters.

Fig. 7. Part of the last section. × 160 diameters.

Fig. 8. Floor of skull, from above, of a somewhat older embryo. × 12 diameters.

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* Professor HUXLEY suggests that it was most probably the Rhynchosaurian Lizard, and not the Sea-turtle, which appeared to me in my observations on that stage. It is well worthy of remark that what Dr. GÜNTHER (Phil. Trans. 1867, p. 599, Plate XXVI. fig. 2) has shown to be peculiar in *Hatteria* (a modern *Rhynchosaurian*), namely the articulation of the pterygoids with the vomers, is normal in the young Bird; in most of the Orders the "mesopterygoid," which is at first a mere extension forwards of the pterygoid, articulates with the corresponding vomerine fork; thus the palatines are thrust aside from each other, and from the mid line. This being the case, there is no difficulty about the separated palatines of *Hatteria* (see Dr. GÜNTHER's note to p. 599); for separated palatines coexist with distinct palato-maxillaries in certain Birds—for instance, in *Emberiza* and *Cardinalis*.

† The *cartilage* is tinted of a lilac colour, and the *cartilage-bones* ochre-yellow; the *membrane-bones* and fibrous tracts are not coloured.

Figs. 9 & 10. Anterior and lateral views of stapes. × 24 diameters.
Fig. 11. Part of palatal rod, from fig. 6. × 160 diameters.
Fig. 11A. Peripheral cells of the same. × 320 diameters.
Fig. 11B. Central cells of the same. × 320 diameters.
Fig. 12. Mandibles and tongue from the above. × 12 diameters.
Fig. 13. Proximal part of mandible of an embryo somewhat older. × 24 diameters.

Third Stage.—Head of Embryo 8 *or* 9 *lines long: middle of* 2*nd Week.*

Fig. 14. Transversely vertical section of auditory sacs. × 10 diameters.
Fig. 15. Os hyoides. × 4 diameters.
Fig. 16. Part of cartilaginous "lingula sphenoidalis." × 250 diameters.

PLATE LXXXII.

Third Stage (continued).

Fig. 1. Basal view of skull, with outer bones removed. × 10 diameters.
Fig. 2. Ditto, with splints and palatal bones. × 10 diameters.
Fig. 2A. Part of the same, from above. × 10 diameters.
Fig. 2B. Section of pterygoid. × 250 diameters.
Fig. 3. Part of fig. 1, from above. × 13⅓ diameters.
Fig. 4. Transverse section of "sella turcica." × 20 diameters.
Fig. 5. Anterior part of notochord. × 250 diameters.
Fig. 6. Posterior part of ditto. × 250 diameters.
Fig. 7. Section of orbital septum and palatines. × 20 diameters.

Fourth Stage.—Head of Embryo 10 *to* 12 *lines long: end of* 2*nd and beginning of* 3*rd Week.*

Fig. 8. End of skull; outer view. × 5 diameters.
Fig. 9. End of skull; inner view. × 5 diameters.
Fig. 10. Half of the same, from within. × 5 diameters.
Fig. 11. Alate portion of septum nasi. × 20 diameters.
Fig. 12. Transverse section through occipital region. × 20 diameters.

PLATE LXXXIII.

Fourth Stage (continued).

Fig. 1. Basal view of skull. × 4 diameters.
Fig. 2. Upper ditto, with splints removed. × 4 diameters.
Fig. 3. Front ditto, with orbital septum removed. × 4 diameters.
Fig. 4. Section of skull with lateral parts removed. × 4 diameters.
Fig. 5. Side view of orbital and nasal regions. × 4 diameters.

Figs. 6–9. Sections of nasal region. × 8 diameters.
Figs. 10 & 11. Sections of orbital region. × 10 diameters.
Figs. 12 & 13. Section of base of interorbital region and part of pterygoids. × 8 diameters.
Fig. 14. The same, below optic nerves. × 16 diameters.
Figs. 15–17. Horizontal sections through "sella turcica." × 8 diameters.

PLATE LXXXIV.

Fourth Stage (continued).

Figs. 1–5. Vertical sections through skull-base. × 7 & 10 diameters.

Fifth Stage.—Head 15 *lines long: Chickens* 2 *Days old.*

Fig. 6. Basal view of skull. × 3 diameters.
Fig. 7. Sectional view of skull. × 3 diameters.
Fig. 8. Side view of skull. × 3 diameters.
Fig. 9. End view of skull. × 3 diameters.
Fig. 10. Horizontal section of skull. × 4 diameters.
Fig. 11. Junction of pterygoid with skull. × 16 diameters.
Fig. 12. Part of pterygoid. × 200 diameters.

Sixth Stage.—Chicken 3 *Weeks old.*

Fig. 13. End view of skull. × 3 diameters.
Fig. 14. Half of front view of skull. × 3 diameters.

PLATE LXXXV.

Seventh Stage.—Chicken 2 *Months old.*

Fig. 1. Vertical section of skull. × 3 diameters.
Fig. 2. Side view of occipital region. × $4\frac{1}{2}$ diameters.
Fig. 3. Part of the same, seen obliquely. × 6 diameters.

Eighth Stage.—Chicken 3 *Months old.*

Fig. 4. Basal view of skull. × 2 diameters.
Fig. 5. Upper view of skull. × 2 diameters.
Fig. 6. Lateral view of skull. × 3 diameters.
Fig. 7. Posterior view of skull. × 2 diameters.
Fig. 7A. Inner view of head of quadrate. × 4 diameters.

Ninth Stage.—Fowls 7 *to* 9 *Months old.*

Fig. 8. Horizontal section of skull, from above. × 3 diameters.
Fig. 9. Horizontal section of skull, from below. × 2 diameters.

Fig. 10. End view of skull. × 2 diameters.

Fig. 11. Front view of skull. × 2 diameters.

PLATE LXXXVI.

Ninth Stage (continued).

Figs. 1–9. Sections through nasal region. × 4 diameters.

Fig. 10. Vertical section of nasal region. × $1\frac{1}{2}$ diameter.

Fig. 11. The same region, from above. × $1\frac{1}{2}$ diameter.

Figs. 12 & 13. Sections of pterygoid. × 200 diameters.

Fig. 14. Section of skull. × $1\frac{1}{2}$ diameter.

Fig. 15. Skull seen from above. × $1\frac{1}{2}$ diameter.

PLATE LXXXVII.

Ninth Stage (continued).

Fig. 1. Side view of skull. × $1\frac{1}{2}$ diameter.

Fig. 2. Horizontal section of skull, upper view. × $1\frac{1}{2}$ diameter.

Fig. 3. Stapes, lateral and basal views. × 6 diameters.

Tenth Stage.—Old Fowls.

Fig. 4. Side view of skull. × $1\frac{1}{2}$ diameter.

Fig. 5. Basal view of skull. × $1\frac{1}{2}$ diameter.

Fig. 6. Upper view of skull. × $1\frac{1}{2}$ diameter.

Fig. 7. Posterior view of skull. × $1\frac{1}{2}$ diameter.

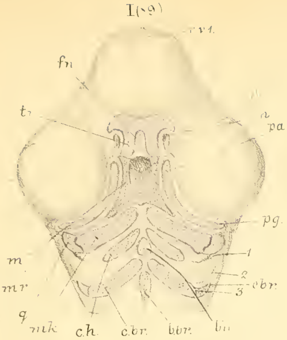
Fig. 8. Sectional view of skull. × $1\frac{1}{2}$ diameter.

Fig. 9. Side view of skull with auditory structures exposed. × $2\frac{1}{2}$ diameters.

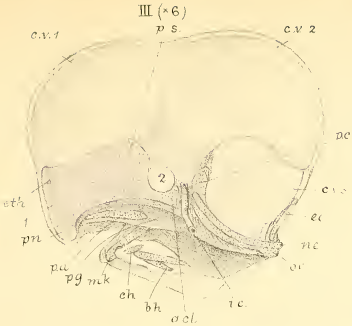
Fig. 10. Lower view of part of nasal septum. × 2 diameters.

Fig. 11. Os hyoides. × $1\frac{1}{2}$ diameter.

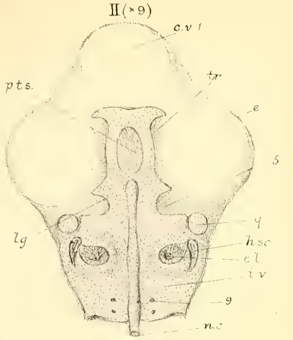
I (×9)



III (×6)



II (×9)



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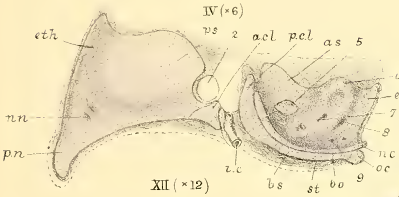

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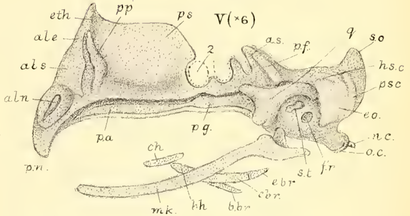

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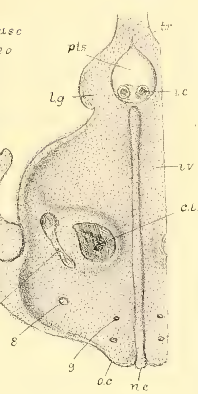

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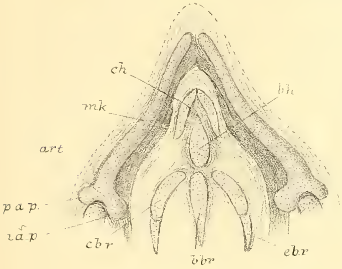

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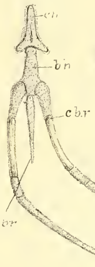

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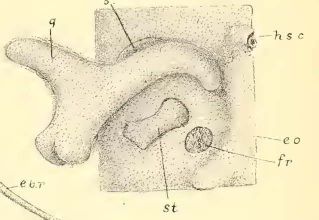

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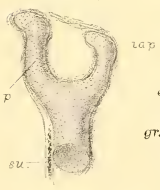

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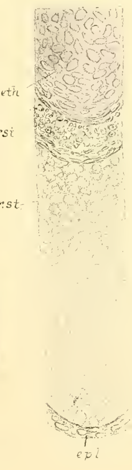

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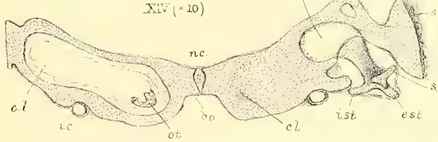

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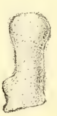

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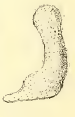

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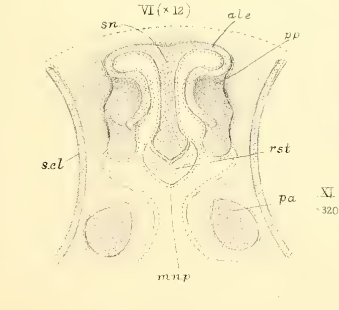

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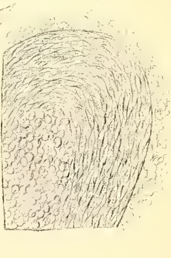
XI^A (×320)

XI.^B (×320)

XI (×160)



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W West imp.

Fowl's Skull.

Figs. I, II. 1st Stage. Figs. III – XIII. 2nd Stage. Figs. XIV – XVI 3rd Stage.

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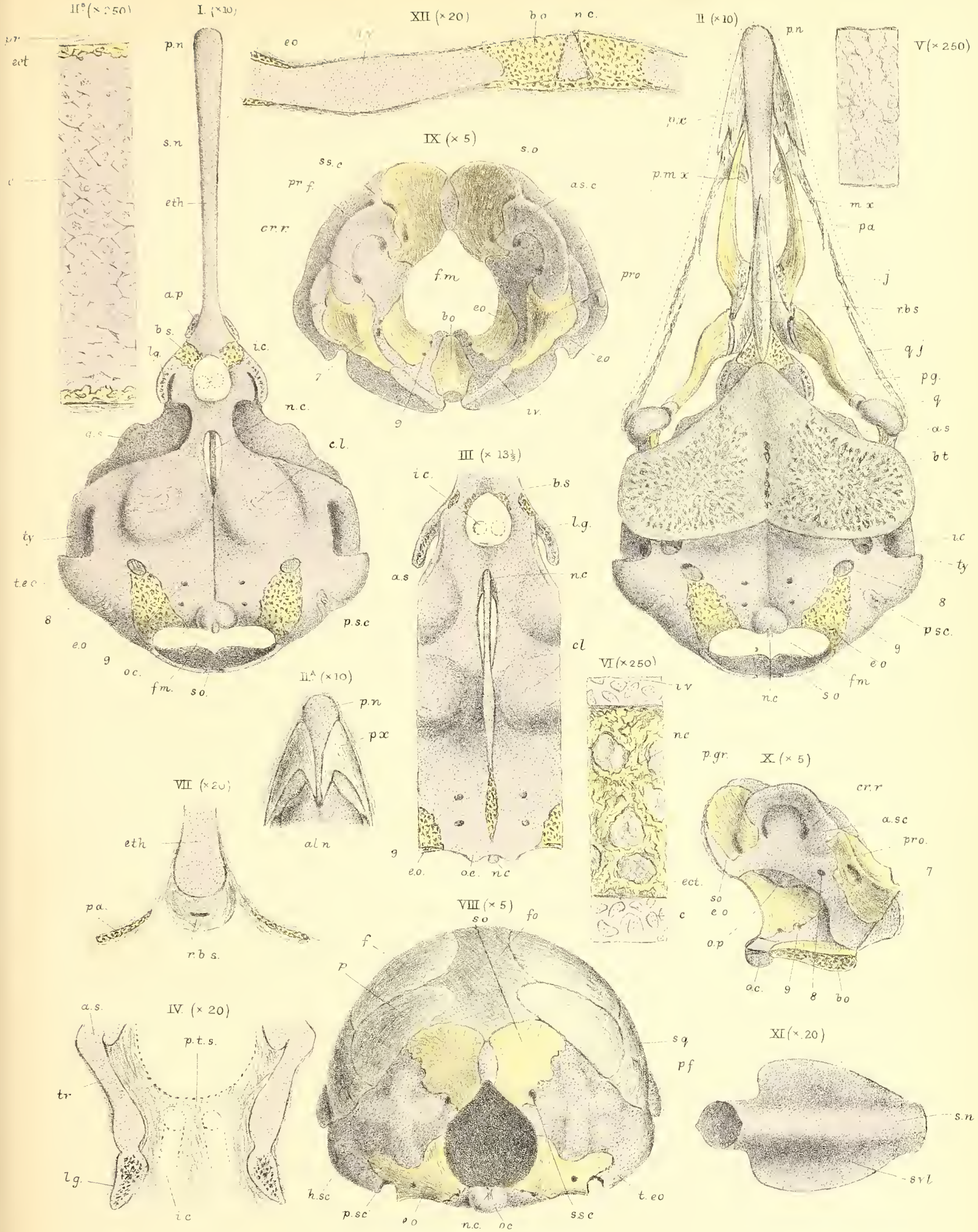

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Fowl's Skull.

Figs. I–VII 3rd Stage. Figs. VIII–XII 4th Stage.

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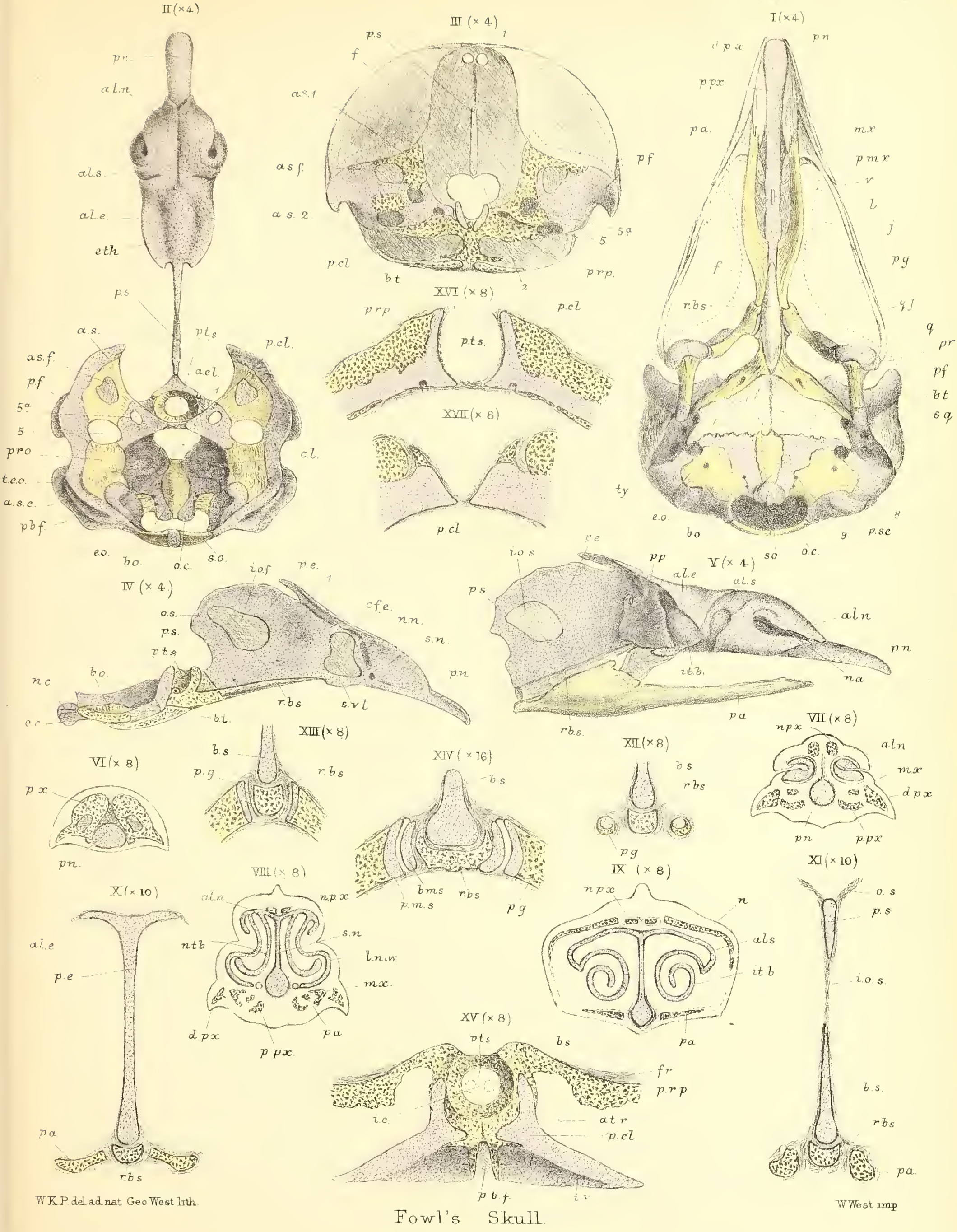

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4th Stage (continued)

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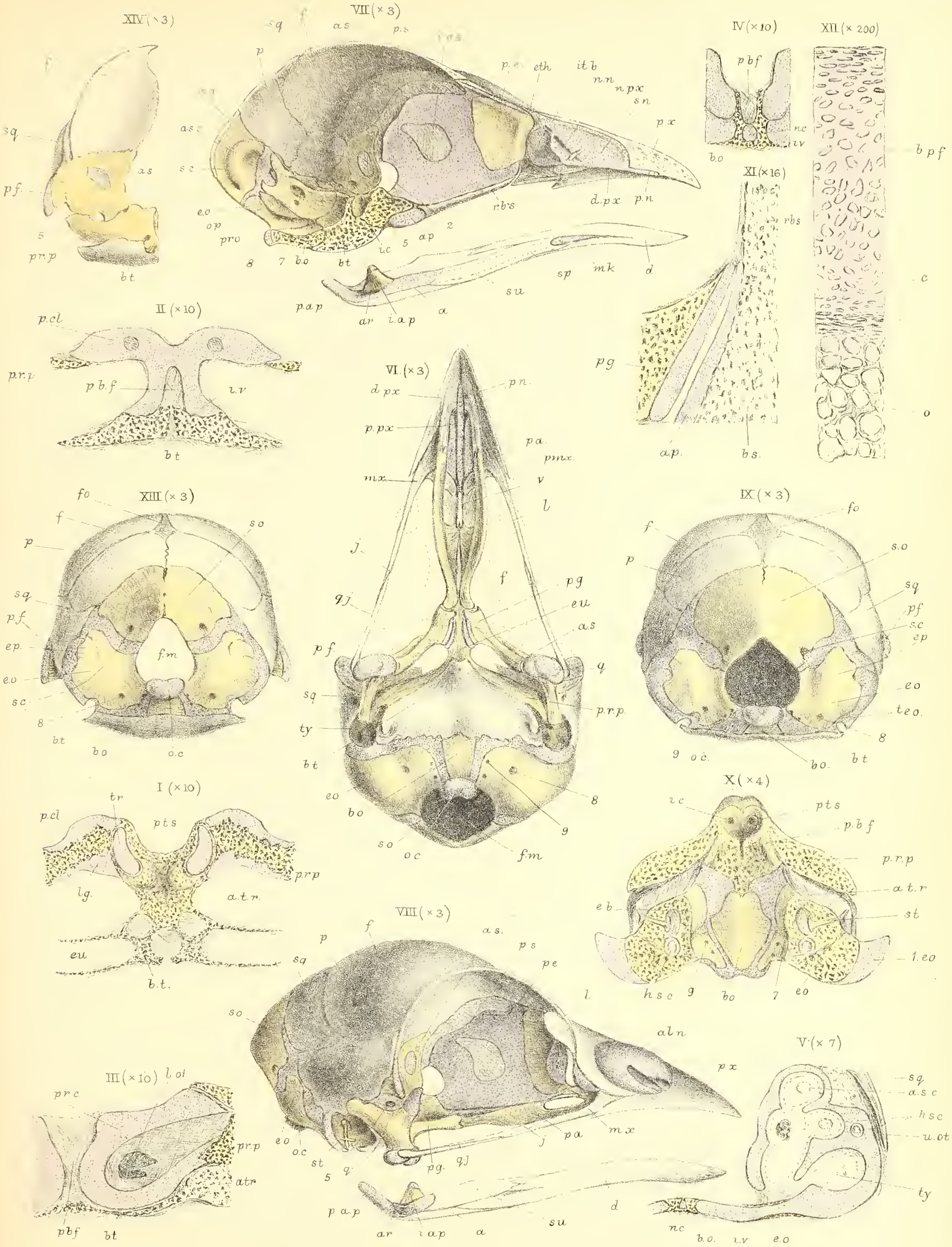

W.K.P. del et nat. Geo. West lith.

W West imp

Fowl's Skull

Figs. I – V. 4th Stage. Figs. VI – XII. 5th Stage. Figs. XIII-XIV. 6th Stage

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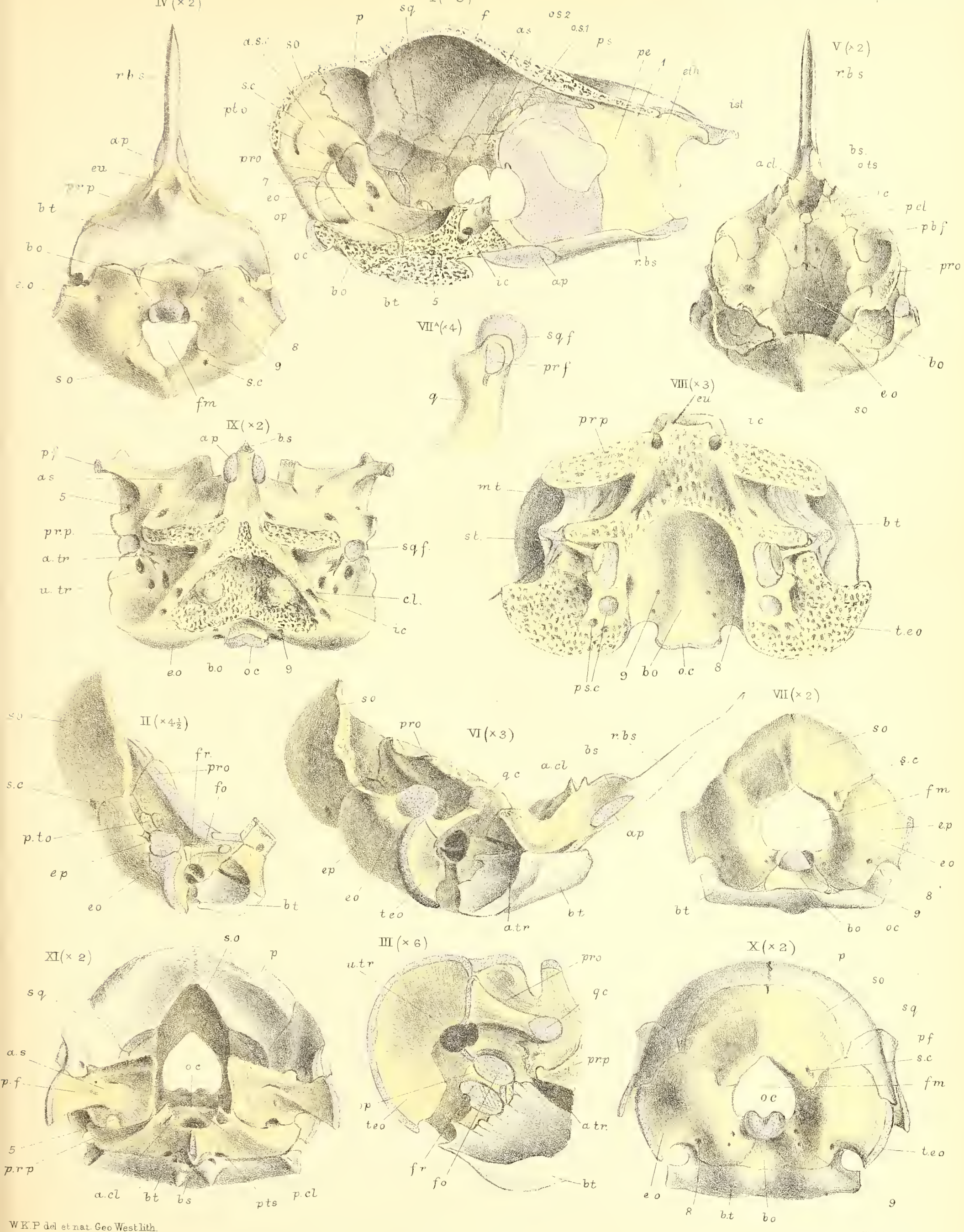

W.K.P. del et nat. Geo West lith.

W West imp.

Fowl's Skull.

Figs. I – III. 7th *Stage*. Figs. IV – VII^A 8th *Stage*. Figs. VIII – XI. 9th *Stage*.

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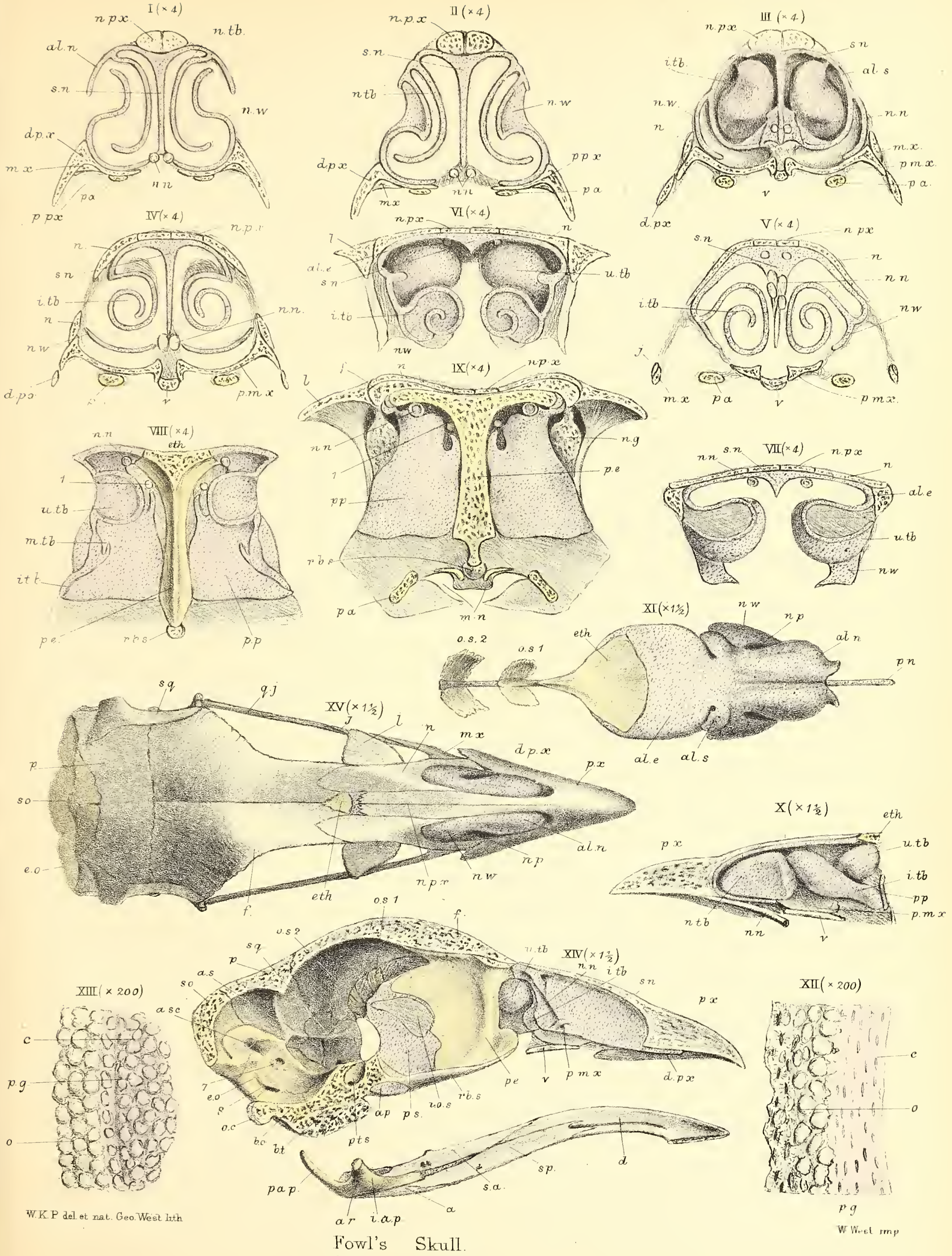

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W. West imp.

Fowl's Skull.
9th Stage continued

BRITISH MUSEUM
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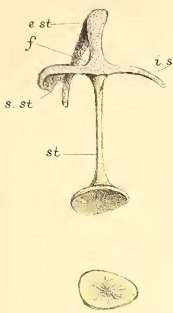
III (× 6)



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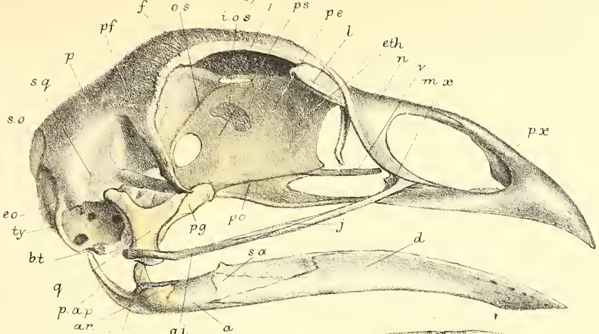

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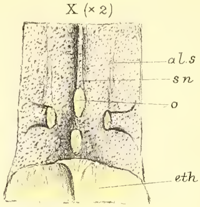

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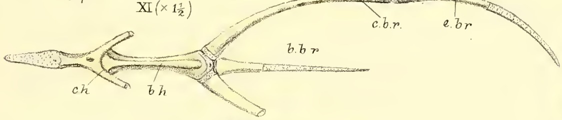

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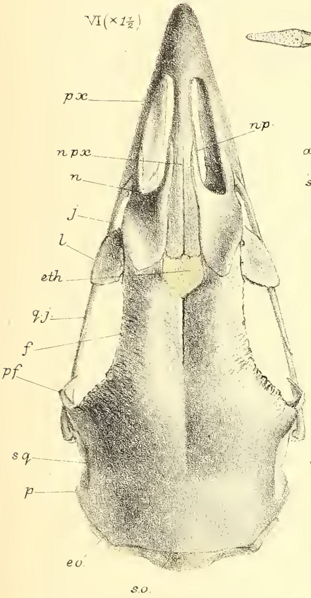

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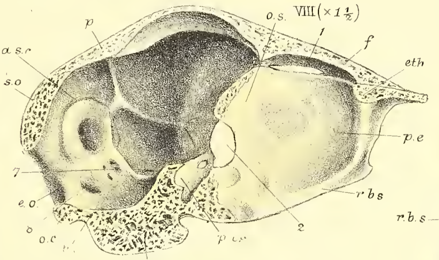

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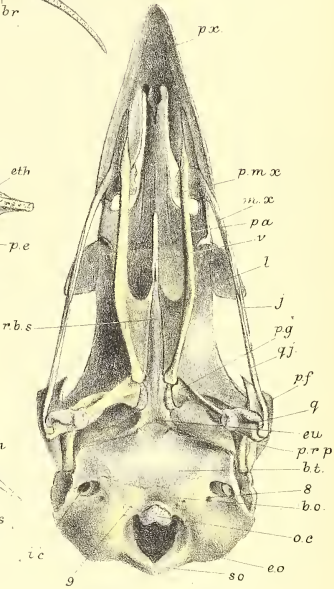

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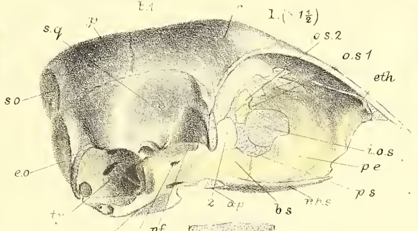

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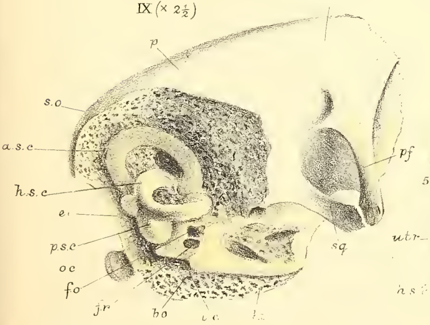

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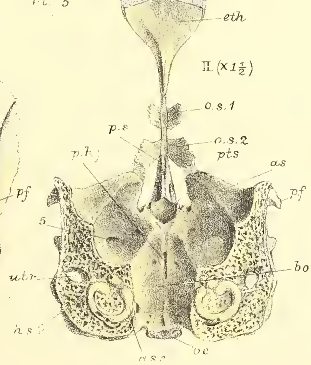

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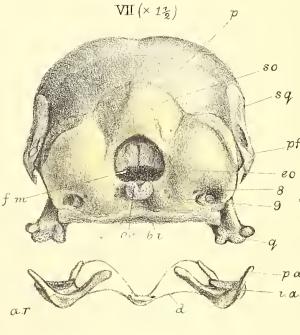

W.K.P. del et nat. Geo West lith.

W West imp.

Fowl's Skull

Figs. I – III. 9th Stage cont. Figs. IV – XI. 10th Stage.

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